RESOURCE CITY:

TAPPING INTO LOCAL PRODUCTION IN APELDOORN

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Abstract

This research demonstrates how a urban context can capture it's productive qualities and natural resources to improve material self-sufficiency and generate more local supply chains. By exploring the significant resource flows around Apeldoorn, this paper proposes how local materials and waste streams can be used within a future development proposal within the city centre. Flows from the surrounding agriculture and forestry, paper industry and urban waste are explored and applied within the re-use of Centraal Beheer, a vacant office building within the redevelopment area. The aim of the paper is to determine the construction applications of local materials as well as the infrastructure and spatial requirements to generate a long term product cycle in the local area.

KEYWORDS: ***LOCAL MATERIALS, SELF SUFFICIENT CITIES, RENEWABLE MATERIALS, URBAN METABOLISM***

1. INTRODUCTION

1.1 Context

A continually expanding society, which is increasingly concentrated within urban environments has incentivised increasing extraction and production of resources for materials, fuel and food. The huge worldwide demand has led to damaging levels of greenhouse gas emissions, substantial biodiversity loss and water stress (UNEP Annual Report, 2019). Complex global supply chains make it difficult to trace entire production processes from extraction, processing and transportation, to end of life. This complexity makes it difficult to improve the social and environmental impact of these supply chains (Hill, 2020). Increasing awareness of the environmental damage caused by distant supply chains and in the context of a global pandemic, there is now even more incentive to make nations and their cities more self-sufficient and break away from the current model of rigid international supply chains to a more flexible local production model. A shift from generic, rigid mass production to a smaller more responsive product cycle that can quickly respond to local, contextual and cultural drivers. Reducing imports and encouraging cities to produce what they consume increases the chances of managing and activating a circular economy. In addition, creating more stable employment opportunities that can be managed on a local level. The Netherlands is targeting to achieve a fully circular economy by 2050 hence cities must undergo re-structuring to introduce closed loop production and consumption systems. Urban and architectural design can catalyse this transition by placing the infrastructure needed to generate the materials needed for an expanding built environment and growing population. To move forward with this approach, new construction should therefore utilise local materials and waste streams within the building fabric as well as accommodate space for long term production and manufacture. Establishing local networks of material flows can enable a culture of sharing which uses local resources efficiently and aims to avoid waste. With developments in automation and digital fabrication, this is making production and manufacture more accessible within an urban context, bringing the supply chain closer to the consumer improving the ability to satisfy individual needs (Hill, 2020).

This research aims to explore these themes within the context of Apeldoorn, a medium sized city within the province of Gelderland currently with a population of around 160,000. The city originates from an agricultural village equipped with royal hunting grounds and a paper mill industry, only establishing itself as a city during the late 20th century through the implementation of the post-war Structurrplan (Hinterthur, 2009). The resulting city centre therefore combines scatterings of low-rise detached houses arranged around village-style greens, generous villas which line the route to the Paleis het Loo and three to five storey twenty-first century construction. Now, redevelopment plans within the area surrounding the station will provide up to 2500 news homes, 100,000 m² of workspace and new leisure facilities, as well as the introduction of new industries and economies.

Figure. 1 Apeldoorn Railway District under development (source: authors own image)

This presents an opportunity to capture the cities historically productive characteristics and introduce self-sufficiency and a circular society run with local resources. The research therefore investigates how local resources and waste streams can generate a supply of materials for use within the built form of the proposed buildings; specifically focusing on the re-use of Centraal Beheer, a currently vacant office building and structuralist icon designed by Herman Hertzberger. This will consider the bioregional characteristics, industries and waste streams to identify a range of raw materials which could be beneficial to the growing city. The research involves investigating the variety of ways in which the natural raw materials can be applied within architectural design as well as what it needed to generate a long term supply. Hertzberger's intentions with the design of Centraal Beheer encourages user-defined, adaptable and multifunctional spaces, hence the architectural materials discussed in this paper align with these design themes, including modularity and design for disassembly. Furthermore, the research also aims to consider how the identified materials could be utilised in the long term, within other urban manufacturing fields that support the growing population such as furniture and household items . Finally, this paper will discuss how the supply and manufacture of local materials within Apeldoorn could benefit the city and increase resilience. While there is an extensive range of sources to explore regarding local materials, this research focusses on a select few which have been identified by the province to be significant and have historical and cultural relevance within the area.

1.2. Research Question

The overall research question for this paper is:

How can existing local industries and waste flows generate a sustainable supply of materials for construction and manufacture in Apeldoorn?

The sub-questions which will be discussed in order to address this question are:

1. *What are the significant local material flows and waste streams which can to be utilised?*

2. *How can the local resource flows contribute buildings materials within the context on Centraal Beheer?*

3. *How can the manufacture and trade of local materials benefit the stakeholders and urban population?*

2. METHOD

The research will be carried out in the chronological order of the sub-questions presented above, beginning with the analysis of Apeldoorn existing significant materials flows and bioregional characteristics (3.1). This involves quantitative and qualitative data collection combined with mapping of environmental characteristics from tools such as PDOK, Geographic Information System (GIS) and other supporting municipal and regional literature. The resources which present opportunity to become a supply of renewable construction and manufacture materials within the context of the research will be identified from the analysis. Section 3.2 then presents how the raw materials can generate building materials for the retrofit proposal. This involves a review of a selection of materials and corresponding examples to develop a potential palette of materials which align with the objectives of the research. Equally this section will consider the quantities of material available to help assess the feasibility. The final chapter will consider how using local materials and a local supply chain could benefit the urban population, as well as presenting any limitations which may be encountered. Therefore, the overall aim is to present a feasible, environmentally and socially beneficial option as to how the Apeldoorn region can harness existing flows to produce materials within the local area.

3. RESULTS

3.1. Local Material Flows

What are the significant local material flows and waste streams which can be utilised?

An understanding of the bioregional characteristic and locally available natural resources form the basis of the research. The environmental characteristic and ecosystems present in Gelderland have played a significant role in shaping the economic and societal development of the urban areas. Apeldoorn's location on the edge of the Veluwe, an extensive forested area which occupies the western half of the region as well as the IJssel river which runs along the eastern side of the city, has provided the city with rich natural resources (see figure.2). A sloping topography between the Veluwe and the IJssel Valley as well as the complex layering of soil conditions led to a network of surface streams which run towards the current city area providing an easily extractable, high quality water supply (Omgevingsdienst Veluwe IJssel, 2013). The purity of the water combined with large forests attracted the paper production industry to the area, which developed into a prominent industry for the Gelderland province which remains today (Omgevingsdienst Veluwe IJssel, 2013). The rich soil conditions equally attracted agriculture, which occupies much of the flatter land between the city and the valley. Combining the agricultural land with grasslands, forests, heaths and meadows, the total land area covered by vegetation accounts for 78% of the total municipal area which demonstrates the green qualities of the city.

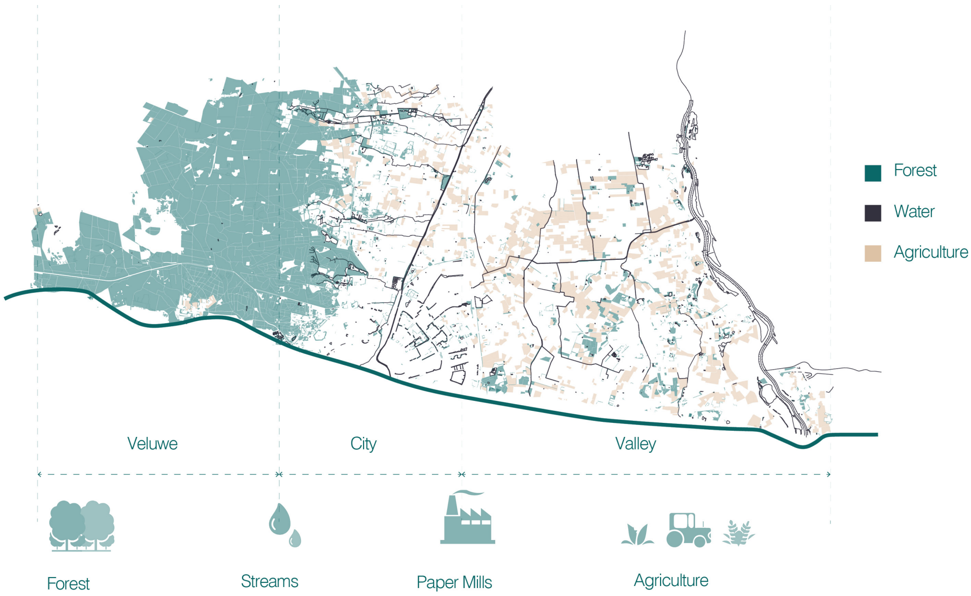


Figure . 2 Veluwe to IJssel River topography and city development (source: authors own image)

The unique environmental attributes correlate to the significant materials flows in the region, which are outlined within a 2019 report for 'Circulaire Atlas Gelderland' a circular economy initiative by the province of Gelderland. The report presents the regional resource flows and corresponding strategies to shift these towards more circular economies. Food agriculture combined with the construction and infrastructure sectors account for 80% of all raw material flows in the region (Royal HaskoningDHV, 2019). The remaining 20% is predominantly from the manufacturing industries, principally paper and cardboard, and consumers distinguished by consumption of products and household waste (Royal HaskoningDHV, 2019). From these environmental qualities and significant flows, four topics are explored and discussed below.

3.1.1. Agriculture:

Agriculture presents a huge resource flow within the region with historical roots and opportunity to be further utilised on a local level (see Appendix A.1). Animal feed from silage maize and meadow grass is the predominant type of crop surrounding Apeldoorn (Royal HaskoningDHV, 2019). The region intends to reduce the amount of purpose grown animal feed and instead use more food waste from the food production industry. Furthermore, they plan to move towards an adjusted diet by reducing the percentage of protein provided by animal products from 63% to 40% and increase the percentage provided by vegetable products from 37% to 60% (Royal HaskoningDHV, 2019). These plans suggest that the current key purpose for farming could shift and opens up the opportunity for a portion of the crop to be redirected for alternative purposes or new crops to the introduced, such as biomass crops which can provide sources of fuel or biobased materials. Miscanthus and hemp are fast growing plants which show promise with regards to variety of sustainable building materials and present alternatives to wood fibres. Farming of miscanthus and hemp are currently present on a small scale in the area, however this could potentially be increased if the demand for animal feed decreases. Additionally, both plants are appealing crops to grow on marginal land due to requiring minimal management and high yield (Grace BBI, 2019). Similarly, contaminated land which cannot be used to grow food products can be instead be utilised for biomass crops which does not lead to competition for land needed for food crops. Within a 20 km radius of Apeldoorn city centre there is approximately 59.5 hectares of marginal farm land which could offer up to 535 tonnes of hemp or miscanthus crop annually for a variety of application within the urban environment.

Cereals and grains, including wheat, rye and barley account for the fourth largest crop production in the area. Straw is a by-product from the harvest of cereals and grains currently used mainly for animal bedding, feed and growth substrates however it is being increasingly used within construction and energy. Within construction, straw can be used stacked in bales as an insulating wall or as thatch for roofing, and also in more processed materials such as non-wood particle boards. Despite the extensive application for straw, there is still a worldwide surplus (Bakker, 2013). A study in the UK suggested that 5.7MT of straw, just under half of all straw produced in the country, is currently under utilised annually and instead ploughed back into the land which results in inefficient carbon sequestration compared to baling (Arup, 2017). The Netherlands previously utilised the abundant local supply of straw during the late 19th century for the manufacturing of strawboard, a type of paperboard, with peak production occupying around 30 factories. However, paper waste quickly became a more abundant source of fibres and replaced straw in the production of the boards. (Adriaanse, 2020). As straw is becoming more commercially viable as a building material, the city of Apeldoorn could take advantage of the area supply to replace imported insulation and roof and infill wall materials.

3.1.2. Paper Industry:

As suggested above, the paper and cardboard industry presents a significant material flow and long standing history within the area. Gelderland is considered the paper capital of the Netherlands, producing 870 tonnes of paper and cardboard products annually of which 73% is packaging made from corrugated and honeycomb cardboard and solid board (Royal HaskoningDHV, 2019). The largest concentration is within the Eerbeek area, which is situated just outside of the border of Apeldoorn (see Appendix B.1). Between 78-85% of all paper products made in the Netherlands can be re-used as raw fibre for new products, thus paper making is highly advanced in term of recyclability in comparison to many other manufacturing industries and close to achieving a fully circular economy (Adriaanse, 2020). In the Netherlands 77% of the fibre material is supplied by paper and card waste, with 14% from virgin fibre from wood pulp which is imported, and 8% of fillers (Royal HaskoningDHV, 2019). There are already many examples of temporary architecture, emergency shelters and furniture designs which have applied the plant based recyclable material in place of plastics and metals, which require more processing and energy to produce and re-use. There is also opportunity to capture and re-use the 15-25% of paper fibres which are currently lost from the recycling process (Adriaanse, 2020) (Appendix B.2). Specifically, re-diverting cellulose waste from the paper mills which cannot be recycled into new paper due to the fibre age, as well as targeting effective collection and sorting of paper waste within the city.

3.1.3. Urban and Household Waste:

Waste from households is a significant material flow in all urban environments which should be viewed as a resource as opposed to waste. Households in the city of Apeldoorn produce 24 Kilotons of organic waste annually which is nearly 10% of the total organic waste produced by province of Gelderland. Much of this is often transported out of the city to be processed for fertiliser, biogas or incinerated (Arup, 2017). Recycling, repurposing or up-cycling unwanted materials within the city can reduce the transportation of waste out of the city to centralised handling units and well as the transportation needed to new import materials and products. Instead organic waste can be used within the city as compost or equally for biogas energy. Improving waste management within the city through better manual collection, sorting, reuse and repair systems can create 10 times more jobs than landfilling or incineration, which are more technology intensive (Zero Waste Europe, 2017) . Green waste such as branches, grass and leaves from gardens, public parks, other natural environment around the city also have the potential to be considered as resources instead of waste. Apeldoorn is being studied as a "Target City" by Wageningen University who are working in partnership with CityLoops, an EU funded project to close the loops of urban material flows. Wageningen are looking into the potential for using the organic waste from Apeldoorn's parks in order to extract cellulose for new materials, such as bioplastics and textiles (Wageningen, 2019). Similarly. GrasGoed is an initiative which collects leftover grass and plant clippings from wetlands on the border between Belgium and the Netherlands. They then develop ways in which the grassy biomass can be used for new materials such as paper, animal feed, fertilisers and biogas (Over GrasGoed, 2019). These ongoing studies show the interest and ambition to improve these local flows.

3.1.4. De Hoge Veluwe:

The quantity of forested land surrounding Apeldoorn has the potential to provide a local supply of timber for the developing city, however this is currently on a very small scale. Due to the small proportion of forested land in the Netherlands comparably to neighbouring countries, 92% of the timber required is imported, meaning the small forested areas can instead prioritise the function of nature and biodiversity (Van der Maaten-Theunissen, 2013). Although, the nearby Hoge Veluwe has 5500 Ha of protected land with some wood production concentrated in the coniferous forested area, including the harvest of pine, larch and douglas spar (Hein, 2011). This produces 2600 m^3 of sawn wood for construction, 1200 m^3 of medium quality wood for pellets and 8000 m^3 of low quality wood for boards (Hein, 2011). Wageningen are conducting an experiment in five areas of the Veluwe to determine how sustainable forestry could be introduced, exploring how harvesting of timber may not be detrimental to the natural environment (Sterck, 2019). For small scale construction and retrofit proposals, this source of timber can be valuable. Engineered timber for large scale construction, such as cross laminated timber (CLT) and glued laminated timber, are increasingly valuable and sustainable construction materials, however there is currently no production of these materials type in the Netherlands. Large regional CLT markets from neighbouring countries (Germany and Austria) are likely to render local production in the Netherlands on a large scale challenging. Thorough European regulation in forestry means that the industry is already advanced and generally regarded as being the most sustainable structural material available. The production of structural timber does not suffer from long drawn out supply chains that this paper is looking to reduce via local materials, and therefore imports of this type of material are considered a manageable and important addition to local materials.

In summary (figure 3), current agricultural practice offers large yields of material, a portion of which could soon be available for non-animal food industries, such as biomass for materials. Utilising straw and marginal land could further create a local supply of resource for the city of Apeldoorn. The paper industry can provide a useful skillset and principles for production which guide the way to new materials, capturing the expertise of handling natural fibres as well as creating an efficient recycling process. Secondly, current paper products have presented the ability to be used within the built environment and generate low-tech recyclable building materials and methods. Paper fibres which are currently lost from the loop, due to contamination or loss of strength and cannot be used in standard paper products have the chance to be utilised in other material types, such as composites. Consumer waste such as organic, paper and cardboard, are easily accessible in an urban environment and should actively be seen as a city resource for new materials instead of waste. Local forests play an important role contributing to natural ecosystems and biodiversity hence large scale timber production would be detrimental to this role. Sawn timber members are available from De Hoge Veluwe which can contribute to Apeldoorn on a greater level.

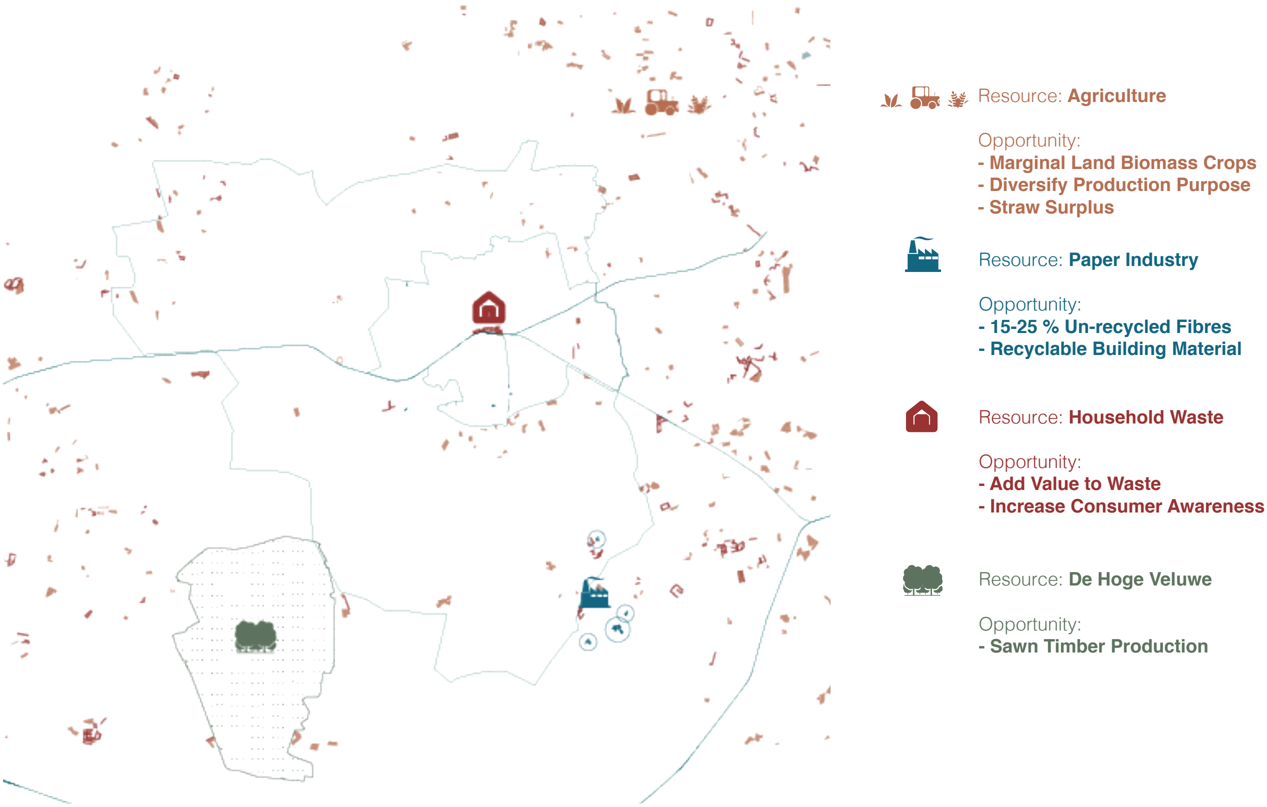


Figure. 3 Summary of potential resources and opportunity (source: authors own image)

3.2. Opportunities for Building and Manufacturing Materials

How can the local resource flows contribute buildings materials within the context on Centraal Beheer?

The flow identified in section 3.1 can provide the ingredients for a local supply of materials which could replace the need for certain imported materials used in the city. This section aims to present how these raw materials could be used to provide building materials within the re-use design of Centraal Beheer, and equally in other long-term purposes needed for an urban population. An overview of the wide range of possible uses for the raw materials was explored (see Appendix C.1) but a selection of materials which most align with the themes of the research are discussed below. The factors which the research considered include:

- The quantity and availability of the raw materials,
- The utilisation of waste streams,
- The prospect of a closed loop cycle,
- The application as modular, customisable and disassemble infill material for Centraal Beheer
- Present as multifunctional materials which can be used for a variety of purposes and hence used in other manufacturing industries such as furniture and household items
- Production methods which relate to existing industries with Apeldoorn

Examples are explored below to present how the local materials can be applied successfully within building design. The diagrams below shown in figure 4 are studies of quantities of material required for a similar approach to be applied to Centraal Beheer. The diagrams focus on Centraal Beheer to provide focus and on an existing structure but the principles can be extrapolated to the wider context of area around the station in Apeldoorn (calculations within Appendix D.1).

3.2.1 External Walls Panels:

Existing Examples

As mentioned in section 3.1, straw is an abundant resource produced from the agriculture surrounding Apeldoorn and is becoming widely accepted within the construction industry as a low-carbon insulating material. UK based company ModCell produce a prefabricated wall and roof panel using a timber frame and straw bale infill which has been used within a range of education and public buildings. These panels were used for the external walls and the roof within Hayefield School in Bath. Straw was sourced locally and construction of panels was completed within their 'flying factory' scheme which are temporary manufacturing facilities within 3 - 15 miles of the construction site and the sources of straw (Pelly, 2014). Despite using concrete for the substructure, the carbon sequestration of the straw panels as well as the CLT structure resulted in the building having an overall negative carbon footprint when considering a cradle-to-gate analysis thus offsetting the first seven years of operational emissions (Pelly, 2014). Being a particularly abundant plant in the Netherlands, miscanthus can be used in place of wheat straw for a very similarly effective straw bale system therefore increasing range of sources for supply. This building method requires minimal processing of materials thus the supply chains is easily achieved on a local scale.

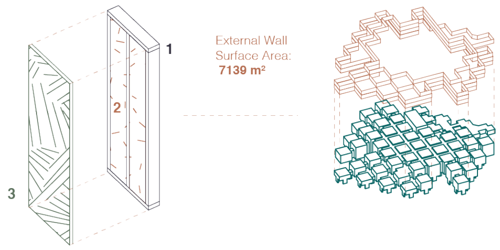
Similar panels can be created using an infill of hempcrete in place of straw bales. When hemp fibres are mixed with a lime cement this forms a non load-bearing highly insulating wall material called hempcrete. The wet mixture can be poured and cast onsite or pre-cast into blocks of panels. The result is a vapour-permeable material which absorbs moisture from the air when humidity is high (Stanwix, 2014). As with straw and any other plant, as hemp grows in absorbs carbon which is then remains stored within the fibres used for construction, thus lowering the embodied carbon of a building. The lime cement used to bind the fibres has much lower embodied carbon compared to Portland cement used in concrete due to the lower temperatures used when burning the limestone (Stanwix, 2014). Prefabricated timber panels infilled with hempcrete are used within the design of Flat House in Cambridgeshire by Practice Architects to demonstrate the capabilities of hemp-based construction. All hemp used within the building is harvested from 20 acres of surrounding farm land (Appendix C.2) (Practice Architecture, 2019). The corrugated cladding panels are also made from hemp fibres, combined with a bio-resin made from agricultural residues such as corn cob, oat hulls and bagasse. The result is a rain screen material which can replace metal and plastic alternatives and further the carbon sequestration of the building. A hempcrete infill requires additional processing steps comparably to straw infill thus requiring facilities currently outside of Gelderland for hemp fibre processing. Facilities of this kind can be found in the north of the Netherlands, roughly 100 km from Apeldoorn.

External Wall Panel:

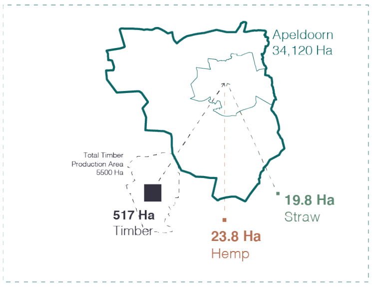
1. Softwood Timber Frame:
Quantity of Timber required: **244.6 m3**
Harvested Area Required: 9.4 % of total supply

2. Hempcrete or Straw Infill, 250 mm:
Quantity of Hemp required: **178.5 Tonnes**
Harvested Area Required: **23.8 Hectares**
or
Quantity of Straw required: **196.4 Tonnes**
Harvested Area Required: **27.2 Ha**

3. Straw Fibre Board, 20 mm:
Quantity of Straw required: **142.8 Tonnes**
Harvested Area Required: **19.8 Ha**

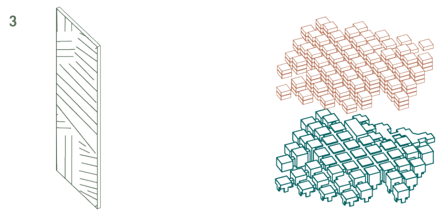


Local Supply:

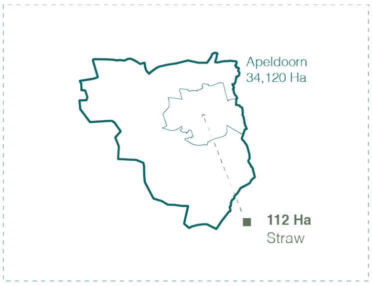


Internal Surfaces:

3. Straw Fibre Board, 20 mm:
Quantity of Straw or Corn Stover required: **330.7 Tonnes**
Harvested Area Required for Corn: **25 Hectares**
Harvested Area Required for Straw: **45.7 Hectares**



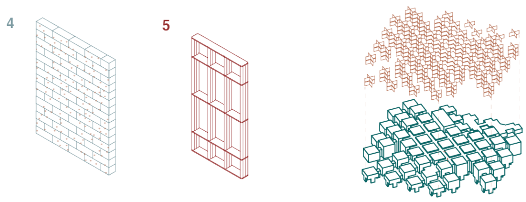
Local Supply:



Internal Partitions:

4. Mycelium Blocks:
Quantity of Corn Stover required: **330.7 Tonnes**
Harvested Area Required for Corn: **25 Hectares**

5. Cardboard Tube Partitions:
Quantity Tubes Required: **11.7 Tonnes (3000 Tubes)**
Households Paper Waste Required: **204 Households**



Local Supply:

Figure 4. Local material applications within Centraal Beheer (source: authors own image)

Applicability to Centraal Beheer + Apeldoorn

Whilst the existing concrete frame of Centraal Beheer is within its intended design life, the external walls are dilapidated, no longer fit for purpose therefore need replacing. The stacked cubic form of Centraal Beheer generates an especially large external envelope therefore accounting for a huge percentage of the buildings use of material. Off-site modular construction, as per the panels described above, align with the site requirements and design intentions for Centraal Beheer, yet can equally be applied to many other types of new construction planned within the development. Based on the panel shown in figure 4, which uses a timber frame with straw or hempcrete infill applied to the full envelope of Centraal Beheer, it is estimated that this will require 244.6 m^3 of sawn timber, which accounts for 9.4 % of the annual production of sawn timber from De Hoge Veluwe. This is a relatively substantial portion of the annual local supply demonstrating the limitation of timber production within the surrounding area. Using a 250 mm infill of hempcrete requires 178.5 tonnes of hemp, using 40 % of the yield that can be produced from the surrounding marginal land. Similarly, if the panels were infilled with straw bales, this would require 196.4 tonnes of straw, which is less than 1% of the annual straw yield in Gelderland. The total farm land required to generate the hemp infill and straw for fibre boards accounts for 0.1 % of the total agricultural land within a 20 km radius of Apeldoorn city centre. This small percentage suggests there is sufficient land to generate a long term supply of material within the immediate area.

3.2.2. Internal Surfaces:

Existing Examples

Timber boards and panels such as Plywood, OSB and MDF are extensively used in construction, especially within modular off-site timber construction due to their compatibility with digital fabrication. Fibre's from agricultural waste and other plants can be used as an alternative to wood fibres to create panels similar to OSB for various construction applications from small scale structures, infill walls, insulation, acoustics, interior finishes, furniture and household items (Dahy, 2017). The plant fibres used can vary from corn, wheat straw, miscanthus and hemp which are mixed with an adhesive, desirably formaldehyde free and bio-based, and then heat pressed into a panel. Using agricultural fibres over wood fibres can be advantageous due to their growth rate comparable to wood and a by-product make the cost of straw relatively low (Kirilovs, 2014). With the increasing demand for large scale timber construction due to the awareness environmental damage from steel and concrete structures, agricultural fibres in place of wood particle boards could relieve some strain on forestry (Kirilovs, 2014). Additionally, the use of straw or other agricultural fibres typically require less processing and energy consumption than wood chip (Dahy, 2017). In 2019 it is estimated that the Netherlands imported 1.9 million m^3 of timber sheet material which includes veneers, plywood, OSB and MDF, while producing none domestically. Thus, based on the abundance of agricultural produce in the Netherlands over wood, agro-fibre boards could present an appropriate import replacement. (Institute for Forestry, Forest Products and Services, 2019). Transforming the raw fibre materials into a panel involves chopping the dry material into consistent size, filtering of any unwanted grains or particles, mixing with an adhesive, heat pressing and trimming to an appropriate size (Compak System, 2014). The choice of adhesive can alter the strength and biodegradability therefore can be suited to the chosen application. To acheive fully compostable boards, lignin from hemp or starch from potatoes can be used (Kirilovs, 2014). Flowers and coloured plants, can provide colours, textures which can be applied to the materials for finishes. Swiss company Organoids, have developed a range of decorative surface finishes and papers made from pressed plants, flowers and straw native to the Swiss alps, ranging from arnica, lavender, cornflower, heather, rose and daisies and can be applied to walls, floor and furniture (Organoid Technologies, 2020). Their surfaces and wallpaper which use a flax backing are compostable therefore can provide an alternative to plastic laminate materials which are difficult to dispose of.

Applicability to Central Beheer + Apeldoorn

Agricultural fibre boards can be used within the prefabricated wall panels described above, and equally within floor and roof systems, finishes and furniture. To produce the quantity of material need within Centraal Beheer this would require using 1.5% of the straw produced in Gelderland annually, using approximately 112 Ha of land. Future uncertainty regarding quantities of animal feed required from corn and straw suggests that contribution of straw or other biomass towards more diverse industries could be an appealing venture for local farmers. As a material of this sort can also be applied with furniture and household items, a long term local supply could replace reliance on imported timber materials and allow for local innovation on the product use, which could be encouraged by local manufacturing hubs. Compatibility with digital fabrication similarly makes it valuable for modern small scale, flexible manufacturing within an urban setting.

3.2.3. Internal Partitions:

Existing Examples

Mycelium composite materials can be generated from the agricultural, paper waste and other organic waste available in Apeldoorn. Mycelium is a root fungus which can be grown on a substrate of organic fibres, such as straw and corn stover, and cellulose from paper waste which binds the fibres together creating a composite material taking the form of the mould it is grown (de Bruin, 2019). Currently the application of mycelium within architectural projects are mostly experimental, such as temporary pavilions, but more widely established within furniture such as lamp shades and acoustic panels. As an entirely biodegradable material, which when exposed to external ground will decompose within 6 weeks, mycelium is currently an important topic of research (de Bruin, 2019). The growth of the mycelium within a mould can take up to 21 days, after which it can be compressed with heat to make boards or left in its mould form and dried with heat (de Bruin, 2019). A substrate containing a high content of cellulose, which can be recovered from the paper mill industry, allows the fungi to grow rapidly and stops contamination by other materials (Lelivelt, 2015). The resulting panels are highly insulating and can achieve a thermal conductivity level as low as 0.08 W/k*m (Xing, Y et al, 2018). 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.

Applicability to Centraal Beheer and Apeldoorn

Mycelium panels and moulded bricks can be used for lightweight and acoustically insulating partition walls. Assuming a 200 mm thickness of mycelium bricks are used for internal partition throughout Centraal Beheer this requires 1778 m^3 of material. It is estimated that 330.7 tonnes of straw or corn stover is needed to produce this amount, using 45.7 Ha of land for straw, or 25 Ha for corn stover. The application of mycelium composite materials within furniture design, packaging and other household items mean production within the city could be far reaching, and replace many imported goods.

Existing Examples

The paper products from the industry surrounding Apeldoorn could be utilised to replace imported materials needed in the city. Widely produced cardboard products, such are tubes, have shown promise with regards to lightweight structures in recent years. The low density, recyclable characteristic and plant-based fibres are appealing when considering the circular economy of building materials. Westborough Primary School in Kent, UK is a single storey social room built in 2001, marking the first permanent paper structure in Europe (Appendix C.3). Paper tubes are used as load-bearing columns combined with cardboard sandwich panels for the walls and roof (Latka, 2018). Strengthening with timber was required at the joints of the structure and the application of water and fireproof layers, which then restrict the recyclability. The strength of paper when wet can be improved through chemical impregnation and still allow the material to be recycled, however the recycling process become more energy intensive (Adriannse, 2020). The lightweight, foldable and recyclable qualities of cardboard make it appealing material when considering adaptable and user driven architectural elements.

Variants of paper materials which use similar principles of paper making yet with a more diverse input of raw materials can have applications within the building industry. ECOR is an emerging company, which began in corporation with a paper mill, produce a composite board made from a number of different waste streams including, paper and cardboard, agriculture, textiles and other plant material (ECOR , 2020). The boards have similar characteristic to a high density paper board, however have the advantage of a highly diverse source of raw materials. An initiative at Schiphol Airport uses the miscanthus waste from mowing the airfields, combined with carton waste from the waste bins, to produce signage boards around the airport. The board are currently finding purpose within a number of applications including furniture, display units, acoustic panels. When used in its raw form, the boards can be fully recycled at the end of use to produce new boards.

Applicability to Central Beheer + Apeldoorn

Using paper board and composite panels like ECOR as construction materials can turn urban waste into much higher value materials. Paper board tubes can make up a lightweight frame for partition walls within Centraal Beheer. It is estimated that around 3,000 could be needed for partition walls throughout the building, as shown in figure. Households within the city of Apeldoorn produce a total of 9,136 tonnes of paper waste per year which can contribute to 10,321 tonnes of paper products per year. The required amount of paper tubes for Centraal Beheer would use 11.7 tonnes of paper accounting for 0.11 % of the total paper products produced from the cities paper waste, hence a very small fraction. This amount can be accumulated from 204 households yearly paper waste, less than 10% of the number of dwellings proposed within the new railway district.

The above shows the wide variety of building components that are currently produced with organic waste materials. The analysis of quantities required for a large building like Centraal Beheer also shows the abundance of these materials and how they could be used of the wider Apeldoorn area. As this is an area of ongoing research, it is expected that the variety and quality of the materials will also increase over time, providing further product streams and local manufacturing opportunities.

3.3. Benefits of Local Supply Chain

How can the manufacture and trade of local materials benefit the stakeholders and urban citizens?

The sizeable agriculture and paper industry in Netherlands currently sells its product to international markets and therefore the contribution of stock to local markets can present a financial loss and thus difficult to justify if the demand is less, however this also means the industries are greatly influenced by foreign economy. Whilst being reliant on a global market means that in times of growth income can be secure, when distant supply chains experience pressure due to unexpected circumstances such as natural disasters, transportation problems, political conflicts, the small businesses contributing internationally can become vulnerable (Hill, 2020). Compared for other parts of the Netherlands, Gelderland's economic structure is largely based on small or medium-sized enterprises therefore may be more susceptible to overseas instability (European Commission, 2010). Having a supply chain in the local area can provide a portion of income which is more stable and more resilient to these external factors. An example of this international dependency is the UK's recent exit from the European Union, which has the potential to cause the Dutch agricultural production value to decline (Van Berkum, 2018). Additionally, in the twenty-first century there is an obvious need to place the value of a supply chain within areas other than financial gain. Environmental and social responsibility are increasingly important factors for a company to address within their business models in order to appeal to consumers and investors.

A report by Wageningen University in 2010 relating to the future of sustainable agriculture in the Netherlands suggest many of the stakeholders see a future in "regional embedding of agriculture and horticulture: small-scale, locally oriented chains, fulfilling more functions than agricultural production" (Meijers, p.7, 2010). There are a number of ways in which the local farmers may benefit from utilising residual and purpose grown crops for local buildings materials. Firstly, any waste currently having little of no value to the farmer which is used within a higher value material can lead to an increased income for the farmer. Transportation of straw is generally inefficient due to its low density and large volume hence use of the straw close to the source can present a more efficient option (Dahy, 2017). As suggested above, utilising marginal land to grow low maintenance crops such as miscanthus and hemp can introduce an additional and diverse income to the farmer. Diversifying crops types can present effective ways of natural pest control, as well as increasing biodiversity termed functional agro-biodiversity (Meijers et al, 2010). Additionally, in conventional food chains, farmers often sell their raw material for a low value compared to the end market price, meaning the value is gained by the many manufacturers, processors and retailers involved (Markuszewska et al, 2012). If the number of stakeholders involved in minimised, this can mean a greater proportion of the money spent by the local consumer can reach the farmer.

Furthermore, as demonstrated by the development of the paper industry around Apeldoorn, local availability of raw material can lead to innovation surrounding purposes and application of resources. If resources described in this research become more abundant and accessible, there is an incentive for manufacturing companies to generate applications for the material, therefore product innovation may increase as a result. By replacing imports with locally made products, there is the potential to keep money circulating within the local economy which can have the ‘multiplier effect’ leading to growth in local economy (Hill, 2020). Jane Jacobs (1985) pioneered this approach stating there were five forms of growth as a result: “abruptly enlarged city markets for new and different imports consisting largely of rural goods and of innovations being produced in other cities; abruptly increased numbers and kinds of jobs in the import-replacing city; increased transplants of city work into non-urban locations as older enterprises are crowded out; new uses for technology, particularly to increase rural production and productivity; and growth of city capital.”

Guallart (2014) suggests as we shift further towards an information society, cities can remove themselves from the global exchange of raw materials and instead offer value to other territories purely through services economies, through knowledge and innovation exchange with minimal transfer of material resources. This ideology is supported by a global initiative Fab City shown in figure 5 which tries to shift away from the industrial paradigm of “Product-in Trash-out,” and instead replace this with more production within cities which lead by a “Data-in Data-out” urban model a global knowledge network that exchanges best practices for the construction of new productive and circular models of urban living(Diez, 2020). Local networks then work together to share resources and educate each other on how to do so.

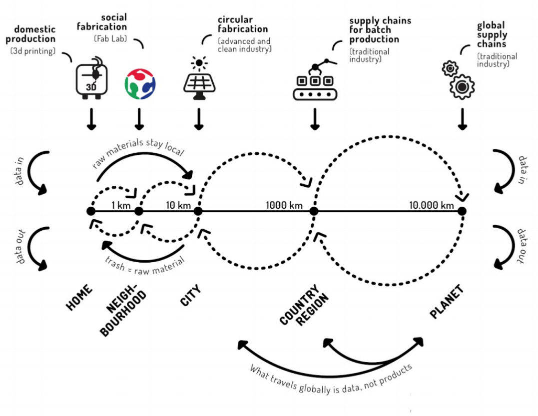


Figure 5. A multiscalar and complementary fabrication ecosystem (source: Fab City)

4. Conclusions

Apeldoorn's situation in the Netherlands provides fertile ground, networks of water supplies, diverse forests and has therefore developed strong productive industries. The research suggests that the existing industries can provide more for city than they currently do which would result in creating a more self-sufficient city. There is a need to introduce new methods for producing, consuming and disposing of resources due to the damaging effects on the planet, which this research suggest can be more easily introduced and managed when on a local scale. To allow urban growth, the resources needed should be found locally, based upon the existing urban metabolism and renewable sources.

The outcome of the research has led to developing a series of speculative interventions which capture the resources identified from the four flows in and surrounding Apeldoorn and convert these into construction materials for use throughout the city (Appendix F.1). This proposes that by introducing a series of production and manufacture facilities, this could provide the infrastructure for a long term strategy which improves material self-sufficiencies. Manufacturing workshops and material storage dedicated to producing building components as suggested by this paper can be accommodated within the existing industrial areas. Centraal Beheer plays a key role in activating this system providing facilities research and innovation surrounding the local materials which can lead to developing further application and demand for the materials within the city. Additionally, space is dedicated to connecting the varying stakeholders and provide a platform for organising and sharing resources efficiently with the aim of eliminating waste.

The methods and overall approach of research can be generalisable to other urban locations, but the research highlights that the specific materials used should be contextual and dependent on the location's historical and industrial characteristics in order to fulfil a truly long term strategy. Local and renewable materials are the focus of this paper, however there are a number of other factors which influence the environmental impact of a material. Embodied energy and water consumption involved during processing of materials was not discussed directly in this paper. As an example, paper manufacturing is particularly water and energy intensive therefore exploring efficient and circular water systems involved in the production process could improve the overall environmental impact of paper materials. Construction and demolition waste is another significant flow which was not explored in this paper, yet when integrated could provide a greater diversity of materials.

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