THE DUTCH MASS TIMBER REVOLUTION: MATURING THE DUTCH MASS TIMBER INDUSTRY WITH CIRCULAR BUILDING PRINCIPLES

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ABSTRACT

The Metropolitan Region of Amsterdam (MRA) is currently working on two pressing issues: A gradual transition towards a circular economy and a pressing housing crisis. This paper explores the potential to expand the local Glue Laminated Timber (GLT) production with embedded circularity principles in order to alleviate the pressing housing crisis. The results indicate that the light weight-to-strength ratio of GLT post and beam construction in combination with pre-fabrication strategies offer a solution to the housing crisis in the MRA. By expanding the GLT production in Amsterdam, control can be seized over the product's life-cycle by applying circularity principles. Circular strategies, including design for disassembly, take-back guarantees, and digital material tracking, are essential in maximising timber's lifespan and minimizing waste generated. Furthermore, the results suggest solutions are not simply about selecting renewable materials, rather than remaining mindful throughout the complete building process. The biodegradability of timber, high labour costs for (dis)assembly, cheap virgin materials and the lack of incentives for circular practices pose significant challenges. The research concludes that a localized GLT industry has the potential to significantly contribute to Amsterdam's housing and sustainability goals. However, achieving this requires systemic changes, including policy reforms, stronger collaboration across the construction value chain and continued research and investment into bio-based adhesives. This research includes interviews with industry professionals and a literary review of circular economy frameworks, the GLT value chain and sustainable sourcing of materials.

Keywords: *Circular economy (CE), Circular Building (CB), Doughnut economics, Timber Construction, Mass Timber (MT), Glue Laminated Timber (GLT), Value Chain, Pre-fabrication.*

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1. INTRODUCTION

<u>Problem statement</u>

The housing crisis in Amsterdam has become a significant burden on the city's growing population (Rood & Evenhuis, 2023). In the Netherlands, a total of 900.000 houses are scheduled to be built before 2030, of which 180.000 in the province of Noord-Holland (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2022). Limited availability of land, climate ambitions and the increasing construction costs in the Netherlands add to the complexity of finding viable solutions (Jonkman et al., 2021).

The current economic model works mostly on a linear framework, where materials are extracted, used, and later disposed of, leading to high levels of waste and the depletion of finite resources. This "take-make-use-dispose" economy (Knight, 2023) has severe environmental consequences. This approach prioritizes short-term economic benefits over sustainable resource management and other issues concerning sustainable prosperity (Mckenzie, 2024). Furthermore, the continued extraction of depletable virgin materials has a multitude of unsustainable socioeconomic issues (Cabernard, L. et al. 2019). The Building industry uses 50% of resources in the Netherlands, playing a pivotal role in this problem (Ministerie van Infrastructuur en Waterstaat, 2023). Buildings and infrastructure were mostly designed with limited regard to reuse or flexibility, limiting option for future circular building strategies and causing an abundance of construction waste (Metabolic, 2023).

The Dutch Government aims to half the waste production by 2030 and become a fully circular economy by 2050 (Ministerie van Infrastructuur en Waterstaat, 2023), requiring all new urban development and public space designs in Amsterdam to have circular strategies (Circle Economy, 2020) (Ministerie van Algemene Zaken, 2023). Due to the risk of carbon tunnel vision (Mckenzie, 2024) (Richardson, 2023) preventing a broader view and luring our gaze away from other pressing societal and environmental issues. The MRA has adopted the doughnut economic model by Kate Raworth's (2017). Through regenerative design principles, this offers architects a framework to look beyond 'less bad' and towards a 'more good' mindset (Hooper et al., 2022). Timber products have great eco-friendly value as a construction material (Van Der Lugt, 2020), but it has not yet reached its circular potential. A study by Metabolic (Metabolic, 2019) estimates there is still €111m worth of timber being incineration or wasted every year in the Netherlands.

Furthermore, the Netherlands has a heavy reliance on imported materials due to its domestic raw material scarcity and high-population density. The same goes for renewable materials such as timber (Teeuwen et al., 2024). The metropolitan region of Amsterdam (MRA) has vowed to develop 20% of all new constructions with timber (City of Amsterdam, 2022), highlighting the growing demand for Mass Timber (MT) products. When the production of goods is outsourced to other countries, the supply chain becomes susceptible to disruptions as seen during the Corona Crisis (ABN AMRO MeesPierso, 2021). Interruptions in the production chain can lead to delays and shortages, impacting the local industry and their consumers (Velthuijsen et al., 2022). Perpetuating the reliance on import may contribute to a weaker domestic skill- and knowledgebase in the MT manufacturing sector. Skills which could be essential in a mature circular MT economy.

Expanding the domestic MT industry could help embed more circularity principles into the core of the Dutch timber building sector, while tackling the pressing housing crisis in the MRA. A mature MT industry can potentially nurture local skills- and knowledgebase of timber and circular building strategies, which is one of the suggested aims by the transition team (2018) of the MRA. This paper will focus on the structure of buildings, since this is the biggest contributor to a their overall waste stream (Van Der Lugt, 2020, pg.59). To narrow the scope further, the focus will be on the production chain of Glue Laminated Timber (GLT) for post and beam construction strategies.

RQ: Could a local Glue Laminated Timber production chain assist the metropolitan area of Amsterdam tackle the acute housing crisis while working towards their circular economy goals of 2050?

In order to get to a structured answer, a set of sub questions is chosen to retrieve intermitted results:

Q1: How could an Amsterdam based Glue Laminated Timber (GLT) production chain help alleviate the housing crisis?
Q2: What does a GLT production chain look like and what is the potential impact of the different links in the chain?
Q3: What are good Circular Building (CB) strategies to adopt and what are possible bottlenecks and risks to consider when using bio-degradable materials such as Timber?

2. Theoretical Framework

Densifying cities

Doughnut Economics

The Doughnut economics framework developed by Kate Raworth (2017) offers a visual representation of sustainable development. The model defines the social foundations with the inner ring, while the outer ring represents the worlds' ecological ceiling. The goal of this model is for humanity to operate within the two rings on all elements shown in the doughnut. planetary boundaries (Richardson, 2023).

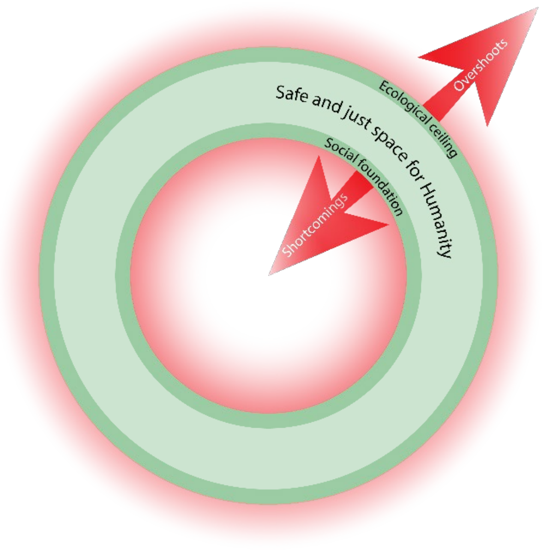

Figure 1 Raworth's simplified donut economics

Figure 2 Visualisation of Kate Raworth's donut economics parameters

Regenerative Design

The theoretical frameworks of regenerative design shows that the construction industry should have a holistic approach to sustainability, not limiting itself by reducing harmful behaviour, but aiming to have to enhance and restore ecological and social systems in our environment through design (regenerative design source).

Circular Economy (CE) and Circular Building (CB)

In literature, the CE has become an overlapping term used to describe harmonised interplay of economic, social, environmental concerns, which encompasses emission reduction, resource protection and waste prevention (M Motiei,2024 & J.Kirchherr). Circular Building (CB) strategies are practical approaches to the principles of a CE within the construction industry. Often requiring designers to look at a building through Life Cycle Assessments (LCA) to identify the impact of each step in the project to make informed decisions. All of these frameworks offer guidance to understand and evaluate a projects broad impact on the environment.

M. Motiei (2024) defines Circular Building by expanding Pomponi and Moncaster (2016) definition of CB: “a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles”. With the extended definition by Leising et al. (2017): “a lifecycle approach that optimises the buildings’ useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a material bank”.

The R strategies / the Lansinck ladder

Looking further at specific CB strategies, the Lansink ladder offers a framework to evaluate the degree of impact for different circular strategies, they are widely used to understand and reduce waste streams for projects. (later expanded with R-strategies model?) The Ladder shows three loop categories: Short loops, mostly aimed at preventing the use of harmful materials; Medium loops, also described as slowing the loop strategies, keeping the material in circulation as long as possible; Long loops, also known as closing the loop strategies involve recycling and recovering the materials at the end-of-life stage (Caldas. L, 2022).

Short loops R0: Refuse, R1: Rethink, R2: Reduce
Medium loops: **R3: Reuse, R4: Repair, R5: Refurbish, R6: Remanufacture, R7: Repurpose**
Long loops: **R8: Recycle, R9: Recover**

Figure 3R-Ladder - RVO.nl

Longer loops tend to require more energy and resources then shorter ones, shorter loops have the preference.

6S - Model (Brand)

Framework about the 6 different layers of a building: Site, Structure, Services, Service plan, Skin, Stuff. (Brand, 1997) The framework suggests the buildings need to be adaptable and able to be refined and reshaped by their occupants. This can be done through a separation of building layers with different life expectancies. Integrating this knowledge into design allowing for disassembly, repairs, etc. can help to get most value from the separated layers and maintain quality at the same time.

3. Methodology

A literature review and interviews with industry professionals are carried out in order to answer the research questions.

Literature studies

A literature study is conducted in order to bolster the authors under understanding of the research field and gain valuable insight into the contemporary questions surrounding circular and timber architecture in the Netherlands. The topics of doughnut economics, circular economic models, GLT value chains and material sourcing will be addressed in the literature studies.

Interviews industry professionals

Interviews were conducted with experts in their respective fields within the construction industry. First of all an Architect specialised in prefabrication, the circular economy, circular building design and circular project development. Another is an industry expert in timber building and mass timber manufacturing. The selection of these specialists is made to gain insight into the complete value chain of mass timber products and their circular implementation within the built environment.

4. RESULTS

Glue Laminated Timber to tackle the Amsterdam Housing Crisis

Q1: How could Glue Laminated Timber (GLT) production help Amsterdam deal with the housing crisis?

In order to tackle the housing crisis with such ambitious goals, the building strategy of the MRA has to focus on high density residential construction. In order to do this, designers have to look to the skies. The Haven-Stad development in Amsterdam's northwestern port region will be denser than any other area in Amsterdam. The average building block could reach up to 30m, with frequent implementation of constructions 60m tall and occasionally finding room for high rise buildings up to 150m in strategic places (Haven-Stad, 2021). These developments will require enormous quantities of building materials, as is to be expected for the development of 40.000 to 70.000 new residences in mixed use neighbourhoods. Add to this, MRA's ambition to make 20% of these developments in timber (City of Amsterdam, 2022), the demand for timber constructions becomes clear. At least 8000 to 14000 new timber building requiring an average of 60m^3 of timber per residence (Van Den Lugt, 2020). This comes down to 480.000 - 840.000 m3 of raw timber for the Haven-Stad project alone. Developing timber buildings with material efficiency in mind could lower the required use of raw materials significantly per residence. A study by LEVS architecten (2024) on the multistorey timber buildings strategies concluded that post and beam construction with bracing in the façade utilises construction material most efficiently for buildings ranging between the heights of 30 to 70m. Due to its light weight, timber post and beam construction saves on depletable resources such as concrete needed for the foundations. When looking at comparison between engineered wood products (EWPs) suitable for post and beam construction, GLT stood out because of some key characteristics. GLT has a scalable production chain, it has a good weight-to-strength ratio, low adhesive content and is reasonably easy to work with. Since it is a tested and proven product, regulations are in place, promising less legislative friction to integrate these products in the upcoming Haven-Stad development in Amsterdam.

Glue Laminated Timber value chain

Q2: What does a GLT production chain look like and what is the potential impact of the different steps of the production chain?

It is necessary to understand the intricacies of the GLT production process in order to make a fair assessment of the material impact. Knowledge of the production process also offers insight in which parts grants control over the final product parameters to implement and optimise CE and CB principles.

Sourcing Timber for Lammelae

Non-sustainable forestry practises can cause deforestation and damage to biodiversity (Nabuurs et al., 2017). Sourcing certified PEFC or FSC timber from sustainably managed forests allow for the use and maintenance of a healthy forest simultaneously by offering forest owners economic benefits they can use to maintain a healthy forest (PEFC Nederland, 2025). The used timber will also store CO_2 in the built environment while it is kept in the loop (Van Den Lugt, 2020). Sustainable forestry enhances the local socio-economic situation and offers stable employment under good and healthy working conditions.

Not all species of timber are fit for the production of efficient structural GLT elements, but there is a variety of possibilities. Softwood is frequently used for MT products due to a combination of availability, durability and workability characteristics. Since the introduction of sustainable forestry programs in the Netherlands, production of domestic forests is limited and programmed to decline the coming years (Kuneman et al., 2023), while demand for MT products is expected to grow. Emissions caused by transport of the timber is minimised when sourcing from forests in close vicinity of the manufacturing facility (interview 2). Amsterdam has great waterways infrastructure, with connection to the river Rhine. This offers efficient access to huge expanses of forests in the west of Germany (Wantzen et al., 2023) among others. The waterway infrastructure allows import of materials from these areas with lowered transportation emissions. Therefore, the available timber of North Rhine-Westphalia (NRW) is also taken in consideration due to its rich forestry industry and vast stock. Scots Pine is the most common species sourced in the Netherlands. Spruce is the most available Softwood species in North Rhine-Westphalia (NRW), while Beech seems to be abundantly available when hardwood is considered (Statistisches Bundesamt, 2024). Though Beech might be more suitable for other types of EWPs due to its material characteristics. Larch is another species worth looking into due to its durability and local availability in both the Netherlands and NRW. Larch has been used to develop MT products such as GLT (interview Manufacturer). With the right treatment and detailing, Larch can be utilised in higher service classes. Larch and Spruce have similar processing steps, requiring little to no extra material and logistic capability within a single facility to use both species (interview Manufacturer). However, due to the more abundant sustainable availability, the main focus of this research will be Spruce for the production of GLT. While GLT is usually made with virgin timber materials as lamellae, alternative solutions using reclaimed timber are being investigated (Built Offsite, 2024). Reclaimed timber stock comes with irregularities including timber species, additives, dimensions, damage, defects, etc. The implementation GLT products made with reclaimed material is still in early stages of development and such technology has not yet matured.

Glue Laminated Timber value chain

Research into the production GLT elements from tree to building element led to the development of the visualisation of a circular GLT value chain found in appendix 1. It expands on different visualisations (Bowers et al. 2017), (Swedish wood, 2024) encountered during the research and the information gathered during an interview with a GLT manufacturing expert (appendix 2.) The following steps of the production usually take place inside GLT manufacturing facilities:

- **Sourcing Certified Timber:** Sourcing certified timber sawn into good quality lamellae

- **Sorting and Quality Control**: Lamellae are scanned and sorted to minimise defects and quality control purposes.
- **Planing**: Lamellae are planed to achieve a standardised thickness and smoothness.
- **Finger-Jointing**: Lamellae are joined end-to-end using finger joints and glue.
- **Pressing**: Layers of lamellae are pressed together to form GLT beams and columns.
- **CNC Machining**: The products are cut and shaped to precise dimensions.
- **Quality Inspection**: The products are inspected for quality control.
- **Surface Treatment (Optional)**: Additional treatments may be applied for aesthetic or protective purposes.
- **Prefabrication (Optional)**: Elements can be assembled into building system in preparation of further on-site assembly.
- **Packaging and Shipping**: Finished products and systems are packaged and shipped to construction sites.

<u>Sorting and quality control</u>

The edged and graded timber from lumbermills is brought to the production plant, where the manufacturer usually reexamines and sorts the timber through their own protocols (interview Manufacturer). This is done to remove more defects and improve the overall quality of the material. Since the timber is not always fit for immediate use, this step is vital in ensuring the quality of the final product.

Usually, the sawn timber products for construction leaves the lumbermill with some defects, resulting in a reasonable but limited quality of sawn timber (interview Manufacturer). Therefore, the manufacturers of Mass Timber elements such as GLT often opts to mill out these defects at their own facilities. This is done by scanning the material for defects, milling them out and subsequently sorting the products based on remaining defects and dimensions (Briggert, A.) (interview Manufacturer). This sorting and indexing is especially important for GLT, because the use of the right type and quality of lumber has significant impact on the structural capacity of the product. Lamellae are granted a quality grading beginning with T followed up with a number ranging based on parallel tension strength of the lamella (Briggert, A.). In GLT beams, the top and bottom 17% require higher quality graded material then the centre 66%, since forces will be more concentrated in the top and bottom portions (Swedish Wood volume 2, 2024). Posts usually are homogenous and consist of higher grade lamellae. The finished GLT product can then get a strength grading which starts with GL followed up by a number based on the bending strength of the beam. This is similar to the strength grading for Sawn timber which starts with the number C when Softwood is applied and the number D when Hardwood is applied, followed by the bending strength of the component.

<u>Adhesives</u>

This is where most of the environmental impact and potential for reuse is determined for GLT. Selecting the right adhesive for the product can ensure better end-of-life strategies while simultaneously determining durability and fire-resistance properties. Getting a grip on this stage seems vital if the products need to have high degree of circular potential. The selection of adhesive for GLT seems to be a balancing act between the material properties of strength, fire resistance, drying time and sustainability (interview Manufacturer). The main adhesive types mentioned by the manufacturer are partially bio-based polyurethane (PUR) and melamine-urea-formaldehyde (MUF) or melamine-formaldehyde (MF) adhesives. Polyurethane adhesives are (partially) synthetic glues and are generally sensitive to UV radiation and don't perform well in fires, making them less desirable for certain use cases and service classes (Messmer & Chaudhary, 2015)(interview Manufacturer). MF and MUF products are more heat resistant and durable in humid environments, increasing overall versatility. However, the curing time of these adhesives is about 4 times as long (interview Manufacturer), making the production slower and more costly. There are more fire resistant adhesives available on the market, but their production has a much larger ecological footprint (interview Manufacturer). To make PUR, biproducts including Nitrogen oxide and Sulphur Dioxide are unavoidable, both scoring negatively on the LCA (Messmer & Chaudhary, 2015). MUF adhesives are similar to MF, but they also contain urea. Urea is also known as artificial fertiliser and is widely used in many industries. The production of melamine requires the heating and pressurising urea to ~400 degrees Celsius and has nitrogen as a biproduct. This process also requires a lot of energy, further effecting the emissions during the production of the additive (Walczak et al., 2023). Since urea is the main resource to create melamine, the LCA of melamine is intertwined with that of urea. As the name suggests, MF and MUF contain formaldehyde, which is known to cause irritation and health issues at high concentrations. Though these higher concentrations are mostly found during the production of products with higher percentages of these adhesives like MDF or particleboards (Sandberg, 2016). According to the manufacturer, this does not cause any health and safety risks within the production facility of GLT (interview Manufacturer).

Compared to other adhesives used in the MT industry, both MF and PUR adhesives have a lower environmental impact (interview Manufacturer). But they still make the cascading and recycling of these products harder and more restricted. To make these materials better suited for cascading at the end-of-life stage, other solutions such as bio-based adhesives are being researched. Although they are currently under performing, research and development into stronger and more reliable bio-based adhesives is being conducted. The viability and impact of Bio-based adhesives using either bio based proteins, lignin or tannin is studied in Arias et al. (2020) . The study does not only show the environmental potential of these bio-based adhesives, but also proves that life cycle assessments can be a useful tool to identify advantages and disadvantages of different products. Though the study admits there are still improvements to be done and questions to be answered about these eco-friendly alternatives.. Chen et al. (2024) describes the soybean protein based adhesive SM-Bio as a distinctive, environment friendly and competitive alternative for the large-scale production of EWPs.

Furthermore, adhesive free laminated timber (AFLT) shows promising potential of eliminating adhesive materials all together. Such products make use of dowels as fasteners between the lamellae instead of adhesives. Production of such EWP have not yet fully matured in the economy and research by Sotayo et al. (2020) into the structural characteristics show lower load bearing capabilities. Furthermore, this seems to be a strategy to bond the lamellae together, but an alternative for finger joining the lamellae in the first place were not explained. While seeing potential environmental benefits of this technology, these considerations plus the fact that regulations are in place for the use of GLT, makes the use of AFLT products not yet viable. In the future however, AFLT products might prove to be a golden opportunity to reduce the environmental impact further while simultaneously increasing their circular potential. With a few additions and changes in the production chain, a GLT facility could include AFLT production in the future.

Circular Building Elements.

Bio-degradable materials such as timber require extra protection from the elements to prevent loss of quality during the storage, transport or (dis)assembly phases. For this reason, the top surface MT elements are sometimes provided with protective foils or finishes (interview Manufacturer). Such protection can be either permanent or removable before the actual assembly of the element. Different strategies can be implemented depending on the function of the elements.

Material for function

Selecting materials for a building product depends on their intended purpose. In certain scenarios, building elements have hard requirements and not all materials can perform effectively. Therefor, the use of renewable materials can be counterproductive. Instead, reusing non-renewable building materials could prove to be the best option. The initial cost of making the product has been paid, better make use of it and postpone the end-of-life stage delaying the waste stream. A perfect strategy does not exists to fit for all cases (interview 2). Designers need to keep considering the full scope of the design problem at hand and understand the broad consequences of their material choices. Remaining vigilant in and keeping the priorities in mind to make informed decisions to mitigating harmful impact.

Slowing the loop - Take-back guerantees

The use of renewable material does not in itself mean a building element is circular, for that to be the case, circular strategies need to be implemented (interview 2). In CE terminology, strategies which postpone the cascading and end-of-life stage of the product are referred to as a slowing the loop strategies (Caldas, L, 2022). First of all, slowing strategies require the product to be of high quality, and they have to be designed in a manner that they can endure multiple life-cycles and use cases. **Reuse** is a high priority strategy since it postpones the cascading for as long as possible in a high value manner by extending its primary use service life and requiring minimal energy. To slow down the loop further, **repair, refurbishment** and **remanufacture** are next in line respectively. These slowing strategies are more impactful then **recycling and recovery** strategies, known as closing the loop strategies in CE terminology (Caldas, L, 2022). If these strategies fail the element is essentially linear because it is discarded and wasted.

Manufacturing companies are already working with takeback guarantees for their building products. For example, a manufacturer of prefab concrete floor slabs is in collaboration with a CB developer and is willing to recertify their materials later in the lifecycle (interview 2). The developer points out that the slabs become more valuable, since they generally harden and can carry more load over time. A MT manufacturer with a retake policy explained that the R-strategies for their products are not yet fully explored or optimised, admitting that the primary reason to start the policy was to give the products a more favourable outcome in LCA calculations (interview Manufacturer). The manufacturer points out there is great value in the material, especially when CB strategies are implemented.

Materials such as concrete, steel, and bricks are often not reclaimed or repurposed, instead piling up in landfills or ending up as low reuse under the tarmac of our highways (Lang & Baggerman, 2024). In the case of renewable materials such as timber, closing the loop is more forgiving. Possible strategies include recycling, incineration or landfilling the timber. Recycling can be done through cascading in the form of strands, chips, fibres, pulp, etc to create new products. In the Netherlands, timber waste streams are classified into 3 different categories (Nijssen, 2022). Category A is used to describe the highest quality, untreated timber. This can generally be reused for product manufacturing through cascading strategies (van der Lugt, 2020). Category B is treated, glued or painted timber. MT with adhesives such as GLT falls into this category. If it is not clear what kind of glues, finishes or paint were used, the material is usually incinerated for energy recovery. Thorough waste stream management however could make the material in this category fit for cascading. Category C is impregnated or treated timber containing toxic additives. These materials cannot be cascaded down and can only be incinerated in a controlled environment for energy recovery or landfilled, with an obvious preference to the former. Incineration can be used to generate power, and helps dispose of elements with toxic contamination, including harmful additives. The linear strategy of disposal is done through landfilling and can often be avoided. At the moment however, timber is not always separated or filtered out of other waste streams and is too often wasted in landfills (Metabolic. 2019).

Circular Building Strategies

> ***Q3: What are good Circular Building (CB) strategies to adopt and what are possible bottlenecks and risks to consider when using bio-degradable materials such as Timber?***

For a building element to be optimally implemented, the building system has to adopt CB strategies. According to an CB industry professional, thinking critically and staying well informed throughout the project to obtain the regenerative design ambitions is a key challenge and requires a well thought out process and thorough collaboration (interview 2). The design team needs to look at the entire lifecycle of the building to get a grasp on the true impact. This corresponds with the theoretical framework of CB (M Motiei, 2024), which emphasizes that CB is a multifaceted and broad subject of which material selection is just one aspect. In the framework, materials selection is part of resource management, one of the 3 pillars of Circular Building. The three pillar are:

1. Resource management
2. Design management
3. Collaboration management

Thus far, we've looked at resource management, and material choice in particular, but it is not possible to design circularly without the other pillars. Many factors will have their part to play in designing Circular Buildings. A key aspect in CB is therefore not per say the material itself, but how the material is used in a circular system.

Demountable design

Buildings can be made out of 100% timber and still be very difficult to reuse because the elements are difficult to disassemble. Such a building shouldn't be considered a circular building, the materials will have to be cascaded down. While another building could be using concrete or steel elements which are easily disassembled and reintegrated in other projects. CB strategies can differ quite a lot and require varying degrees of designer input. A design can be movable, meaning it can be (dis)assembled and rebuild multiple times with very little adaptations or designer input. While other strategies focus more on adaptability and flexibility and would require careful considerations from a design team. Adapting strategies include:

- Moving (assembling & Disassembling)
- Rearranging
- Expanding
- Splitting
- Topping up
- Flexible building plan

The reuse cycle of a building element could look like this:

Figure 4 Suggested reuse cycle of a building elements

Pre-fabrication in building system

Building in a controlled environment allows for high precision and increased overall quality of the products before they are put into the building stock (interview 2). The increased quality ensures a longer lasting system and more potential for high level R strategies to be implemented. Using pre-fabrication strategies also helps mitigate some of the circular building complexities associated with the vulnerable building elements. Much of the assembly and disassembly of the building system is done in a controlled environment and exposure to the elements is minimised. Furthermore, when the material is integrated in an entire building system or module, the vulnerabilities can be mitigated though the use of more durable or expendable materials.

Low cost of virgin material and expensive labour

Currently, the price of virgin materials is relatively low. Circular buildings require extra labour to assemble and disassemble the project carefully. Since the cost of labour is relatively high, it is tough to financially compete with projects using virgin materials (interview 2). Increased carbon taxing could help in this regard (interview 2). The added environmental costs would affect virgin depletable materials in particular, making renewables and reclaimed materials more competitive.

Cultural stigma.

Not everyone sees the value of used materials the same way. A cultural shift has to take place to make sure we value reused materials according to their capabilities, not on cultural stigma which brand reused and second hand materials as inferior. Some materials can become more coveted and valuable over time, while other retain their worth or slowly deteriorate. But even deteriorating materials can gain in value when their aesthetics and imbedded stories are valued by the community.

Complex Logistics

Circular strategies include the reuse and storage of buildings and their components, the logistics that are involved can get quite complex. There is a lot of collaboration and planning required to construct a successful circular building strategy (interview 2). The logistics alone can make or break a project. Storage complexity scales with the size of the building and amount of components. Stacking height of elements, overshooting the self-capabilities of components can cause damage and loss of value (interview 2). Digital infrastructures like Madaster can help keep things organised. Tracking elements throughout their life-cycle allowing designers to get a good assessment of the remaining value of elements. Digital infrastructures and QR codes can also assist designers planning out the storage phase of their buildings, simplifying systematic approaches and minimising inefficient storage of buildings elements.

Quality control and Maintenance

Besides having a good quality building elements, having a building system and strategy which protects the element during the different phases in the life cycle is detrimental. Bio-based materials, such as timber can be more prone to damages than others. They might require extra protective measures during storage, (dis)assembly and transport further complicating the logistics.

Regulatory barrier and policy makers

According to a circular building specialist (interview 2), there is currently no special certificate available for circular buildings. Resulting in the need to recertify a reused building and their building parts according to laws set for new buildings every time it is rebuild. The development of certificates based of circular building principles could lubricate the process and make CB more viable.

5. CONCLUSION

In conclusion, the linear economic models prioritizing economic prosperity seem insufficient and unsustainable. Because of pressing environmental issues, opinions on climate change are starting to shift. The expansion of the domestic GLT industry in the MRA has the potential to not only alleviate the housing crisis but also contribute significantly to the region's circular economy ambitions. GLT based post and beam construction is scalable strategy with high material efficiency, particularly in high-density developments like Haven-Stad. Its lightweight nature reduces foundation costs, while prefabrication accelerates construction timelines. Localizing GLT production could reduce reliance on imported production and help embed CE strategies in these new building elements. An insight into the production process of GLT suggests that sourcing and processing of timber into lamellae is best left to local forestry industry. While taking control of the production can give control over key decision-making steps that which affect the viability of circular strategies. Overseeing the production also allows for the implementation of take-back guarantees, digital infrastructures to simplify logistics and R-strategies for the products that are put into the building stock. Choosing the appropriate material for the function of the element remains to be the first priority. Sometimes, the use of renewable materials can be counterproductive and the choice of reusing durable materials can prove to be more beneficial. Furthermore, resource management is only one of the 3 pillars for Circular Building. Implementing CB strategies around design and collaboration management are a necessity to true circular building. Effective strategies include: pre-fabrication, demountable design, flexibility and adaptability and these can prove extra effective in mitigating environmental impact when using bio-degradable materials such as timber.
While the current economic and regulatory frameworks may pose barriers, the increasing demand for sustainable housing and the growing awareness of environmental issues provide a strong incentive for change. The MRA's commitment to timber construction and circular principles positions it as a potential leader in sustainable and circular urban development. By fostering collaboration across the building sectors, Amsterdam can use the housing crisis into an opportunity to push the building industry into a resilient, circular future.

6. DISCUSSION

This paper has focuses on structural building strategies with material efficiency and circularity as the main parameters. Structure constitutes 60% of the environmental impact of a buildings materials. To create a more complete circular building strategy, the other 40% should be accounted for as well. Further development of the other building elements and modules such as interior walls, building envelopes and installations is therefore required. Each having their own complexities. This research does not investigate the end of life strategies themselves or how engineered wood products such as GLT can get refurbished, repaired and reintegrated. Rather, it investigates the systematic logistic complexities involved with slowing the loop R-strategies. More in depth research should be conducted to include specific R-strategies per EWP.

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