# BUILDING WITH RECYCLED PLASTIC MATERIALS: EXPLORING THE CIRCULAR POTENTIAL OF POLYETHYLENE-ALUMINUM (POLYAL) AND MIXED PLASTICS (DKR350)

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***ABSTRACT***

*One of the challenges for the recycling industry is the lack of sufficient (specific) recycling applications for materials recovered from plastic waste streams. This research explores the potential of recycled plastic materials, particularly polyethylene-aluminum (PolyAl) and mixed plastics (DKR350), for use in construction, focusing on post-consumer, source-separated waste streams. As plastic waste is a major environmental challenge, the construction industry offers an opportunity to reuse these materials. The study examines the technical performance, design flexibility, environmental sustainability and economic viability of PolyAl and mixed plastics and compares them with traditional materials (wood, concrete and steel). It also evaluates how different production techniques affect the properties and applications of these recycled materials in construction. The central research question is: "What recycled plastic materials and related production techniques are available to be used in housing design and construction?". By addressing barriers to the application of recycled plastics, this research aims to promote circular economy initiatives and encourage the use of recycled materials in sustainable, environmentally responsible housing solutions.*

***KEYWORDS:*** *Recycled Plastic, Materials, Polyethylene-Aluminum (PolyAl), Mixed Plastics (DKR350), Design, Circularity, Sustainability, Architecture*

## I. INTRODUCTION

Plastic has become an essential material in modern life and plays a crucial role in various industries thanks to its versatility, durability and cost-effectiveness. However, the current linear model of plastic production and consumption is not sustainable. The exponential increase in plastic production has led to significant environmental problems, with plastic waste remaining largely non-biodegradable, accumulating in landfills and polluting ecosystems. Moreover, plastic production and disposal rely heavily on fossil fuels, contributing to greenhouse gas emissions and exacerbating climate change. In response to these environmental problems, the use of recycled plastics in construction is emerging as a viable solution. However, their use remains limited due to concerns about structural performance, durability and aesthetic appeal. Overcoming these barriers requires a better understanding of the reuse of plastic materials and innovative strategies to improve their properties. This study examines the potential of two recycled plastic materials - polyethylene-aluminum (PolyAl) and mixed plastics (DKR350) - specifically targeting their integration in residential construction, derived from post-consumer waste streams. The study examines the technical performance, design flexibility and environmental and economic aspects of these materials and explores how different production techniques such as compression molding and injection molding affect their properties and applications in the construction industry. The central issue this research addresses is the need to keep plastic waste away from polluting the environment, landfills and incineration by expanding its use in construction. As demand for sustainable building materials increases, rethinking plastic waste as a resource rather than a burden offers significant opportunities for circular economy initiatives. By bridging the gap between the theoretical potential and practical application of recycled plastics, this research aims to advance the role of these materials in creating environmentally responsible, sustainable and aesthetically feasible solutions for the built environment.

## II. Understanding Materials and Production Techniques

Plastic waste has become a pressing environmental challenge, with post-consumer plastic packaging accounting for approximately 44% of global plastic waste (Plastics Europe, 2022). The recycling of post-consumer household plastic waste involves a complex chain that generally consists of three key steps: collection from source-separated households waste (PMD: Plastic / Metal / Drink cartons) or post-separation from mixed household waste, sorting of the collected materials and processing for recycling (Jansen et al., 2015). The report by Klingenberg et al. (2024) highlights that post-separated waste is often disadvantaged due to contamination and the presence of impurities, which lead to material quality degradation. To ensure a cleaner input stream and produce stronger, more reliable recycled materials for construction use, this research will focus exclusively on source-separated post-consumer plastic waste streams, collected in the Netherlands via PMD systems.

After collection, source-separated waste is sorted using the DKR (Deutsche Gesellschaft für Kreislaufwirtschaft und Rohstoffe mbH) system, which enables efficient sorting strategies. The system classifies post-consumer plastic waste based on material composition (e.g. minimum purity and maximum contamination), properties and recyclability (Kooijman & Wilke, 2015).

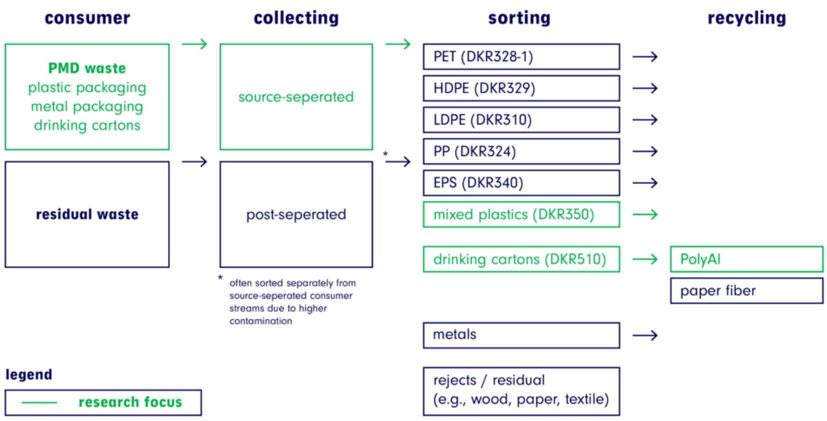


Figure 1. Post-consumer plastic packaging waste to recycling chain (Created by the author)

Plastics that are not recognized as mono-materials, drinking cartons, or metals during PMD sorting are placed in the DKR350 (referred to as 'mixed plastics' in this research) stream (Nedvang Foundation, 2018). This stream contains valuable plastics, due to process inefficiency and packaging design (e.g., multilayered packaging), that could potentially be redirected to higher-value recycling (Van Rhijn & Brandsma, 2022).

DKR510 refers to the sorted stream of drinking cartons, a multilayered packaging material. During recycling, the paper fibers can be separated from the polyethylene-aluminum composite, known as PolyAl, which has significant recycling potential. According to Robertson (2021), recycled materials based on DKR510 show strong potential for applications within the construction industry.

One of the challenges faced by the recycling industry is the lack of specific application opportunities for materials recovered from waste streams. While solutions exist for recycling mixed plastics and PolyAl, this research explores further strategies for utilizing these recycled waste streams, with the goal of reducing landfill and incineration.

## 2.1. PolyAl

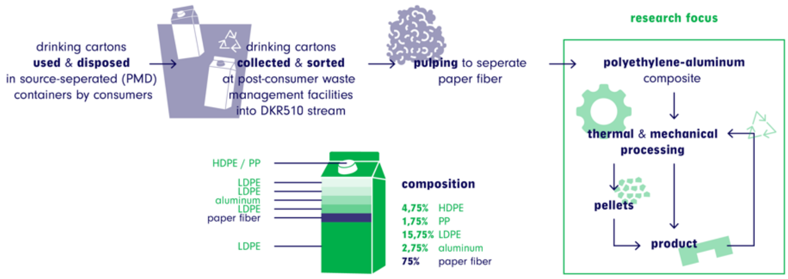


Figure 2. Resource origin and composition - PolyAl (Information from (Bischoff et al., 2023), Created by the author)

After the paper fiber pulping process, PolyAl is the composite material remaining from drinking cartons, consisting of high-density polyethylene (HDPE) or polypropylene (PP) caps, (linear)low-density polyethylene ((L)LDPE) film layers and an aluminum layer embedded within the packaging (Bischoff et al., 2023).

Several case studies already demonstrate the application of the DKR510 residual stream in buildings. The material, including the paper fibers, is recycled by the company Recoma (see Appendix Case Study 1A) into 100% recyclable construction panels, which can replace materials like plywood. Similarly, Ecopeal produces recyclable construction panels based on the PolyAl stream, which can be used for roofing, flooring, facade cladding and interior elements such as cabinetry (see Appendix Case Study 1B). Composite boards, which are among the most commonly produced, are lightweight and water-resistant. Composed primarily of polymers, the material retains a low overall weight, while the inclusion of aluminum contributes to a slight increase in stiffness (Bischoff et al., 2023). PolyAl exhibits considerable potential for circularity and closed-loop recycling systems. Used PolyAl products can be reintroduced into the recycling process alongside new material derived from drinking cartons, ensuring a continuous and sustainable reuse cycle. In addition to its recyclability, Robertson (2021) concluded, based on multiple research studies, that the properties of PolyAl demonstrate significant potential for durable and cost-effective construction applications. Valim et al. (2015) demonstrated that humidity and UV radiation can slightly degrade its mechanical performance, though not enough to render it unfeasible for construction use. Similarly, Sanchez-Alvarez et al. (2019) highlighted PolyAl's excellent thermal insulation (thermal conductivity of 0.22 (W/m.K)), waterproofing capabilities, high durability, exceptional resistance to breakage, acoustic insulation and resistance to fungi and bacteria.

Its versatility is demonstrated through its ability to be extruded into quality extruded granulate (e.g. Plastigram in Sokolov, Czechia) or pressed pellets as produced by Recon Polymers in Roosendaal, The Netherlands (see Appendix Field Research 2C). These pellets can be transformed into new forms using a wide range of production techniques, as outlined in Chapter 2.3.

## 2.2. Mixed Plastics (DKR350)

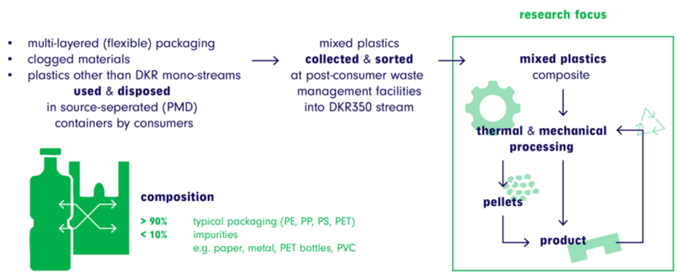


Figure 3. Resource origin and composition – mixed plastics (DKR350) (Information from Genuino et al. (2022) and Der Grune Punkt (2009); Created by the author)

Mixed plastics (DKR350) make up a significant proportion of output streams from sorting facilities and include plastics that cannot be categorized within the mono-streams of the DKR sorting system. This category includes multilayer packaging difficult to separate, plastics excluded from the DKR system, clogged or contaminated items and packaging that is misclassified due to inefficiencies in the sorting process (Van Rhijn & Brandsma, 2022). The composition of the sorted DKR350 stream can vary significantly; however, it is often rich in polyolefins (PE, PP, PS). To ensure the DKR stream meets the required quality for further production, restrictions are imposed on its composition. The output must consist of more than 90% typical packaging plastics, including PE, PP, PS and PET and must contain no more than 10% impurities. Impurities include other materials with a subdivision of: paper and carton (< 5%), metals (< 2%), transparent PET bottles (< 4%), PVC (< 0,5%) and other materials (e.g., glass, wood and textiles) (< 3%) (Plastic Pact NL, 2022).

Despite the changeable properties of mixed plastics, they hold significant potential for applications in construction. This is exemplified by the company Save Plastics, which emphasizes the importance of rethinking the material's perceived limitations: "Plastic material is slack, but you have to think this around. Turn it into a quality." The company has demonstrated this concept by utilizing mixed plastics to create finishing for tiny housing (Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat, 2017). Additional examples of Save Plastics' work, including the Save Cabin initiative, are detailed in Appendix Case Study 1C. Other companies, such as GovaPlast and Lankhorst in The Netherlands, have also demonstrated the utility of mixed plastics in creating durable structural components with lifespans exceeding 50 years. These components are used in various applications, including outdoor furniture, decking and infrastructure. Lankhorst, for instance, developed a facade panel system using its KLP material, which is known for its long life, low maintenance requirements and UV, water and weather resistance (see Appendix Case Study 1D). While most products are black, other but only limited color options are available upon request. (Lankhorst Recycling Products, n.d.)

The application of recycled mixed plastics provides durable solutions for exterior building applications, but their use in interior spaces is less common compared to PolyAl products. This can be attributed to the utilitarian or industrial aesthetic that mixed plastics tend to have, which may not align with the aesthetic preferences typically found in interior design. They are suitable for simple structural applications, demonstrating structural potential, but are not ideal for situations where high structural strength is required. Chapter 3 will delve deeper into the materials parameters, assessing its properties. Based on this analysis, conclusions can be drawn regarding areas where the recycled mixed plastics and PolyAl material may be less favorable, leading to potential solutions that will be explored in Chapter 4.

## 2.3. Production Techniques

During recycling and processing, PolyAl is converted into pressed pellets, produced by Recon Polymers, and extruded granules, as exemplified by Plastigram in Czechia. Mixed plastics, on the other hand, are processed into extruded granules, agglomerates and ground materials like flakes. Companies like Govaplast (2024) source these mixed plastic materials in Western Europe, while Lankhorst specifically obtains them from Germany (Bergsma & Bijleveld, 2017), in this research referred to as recycled resource production.

The study by Saleem et al. (2024) demonstrates that recycled mixed plastic waste has a significantly lower carbon footprint compared to virgin-produced PE or PP. Combined with their economic viability, this makes the use of recycled mixed plastic waste an attractive solution for promoting the circular economy.

In this study, the focus shifts to converting this resource into building components. When production techniques are discussed, specific reference is made to methods that are possible to further process pellets and granules already produced during the resource production stage. Pellets and granules serve as a versatile foundation for the five production techniques discussed in this research: injection molding, extrusion molding, intrusion molding, compression molding and 3D printing (fused granular fabrication, or FGF). For detailed representations and specifications of these techniques, refer to Appendix 3A-E. These techniques, combined with the versatile general properties of plastics, which also apply to recycled PolyAl and mixed plastics, facilitate the production of building components with flexible designs and structural characteristics.

PolyAl shows significant versatility in production techniques. For example, the panels produced by Ecopeal demonstrate the potential of compression molding (see Appendix Case Study 1B). Aectual, a company based in the Netherlands, demonstrates the potential of 3D printing to create aesthetically pleasing objects, such as partition and facade panels (see Appendix Case Study 1E). In addition, NewPal produces pallets by injection molding (see Appendix Case Study 1F), which underscores the structural integrity of the material, as these pallets must bear significant weight and withstand impact forces. All of these applications represent fully circular solutions, using recyclable PolyAl material to promote sustainability.

Companies working with mixed plastic recyclate usually use simpler techniques such as extrusion and intrusion molding, which are often used to make coarser products. Govaplast (2024), for example, uses intrusion molding, a variant of extrusion molding, where the mold does not allow for continuous components. Lankhorst also demonstrates a more advanced approach through its Custom Mouldings vision, where the company uses injection molding to provide more refined solutions, improving the versatility and detailing of end products (Lankhorst, n.d.).

Several critical factors must be considered when choosing a production technique to manufacture a part intended for a specific purpose.

As highlighted by Better Future Factory's field research (Appendix Field Research 2A), the choice of production method significantly affects the orientation and distribution of molecules in the material. This molecular alignment affects not only the mechanical properties, such as stiffness and strength, but also the sensitivity of the material to dimensional changes, such as shrinkage and expansion and the directions in which these changes occur (Whitehand, 2015). Compression molding results in a random, isotropic distribution of molecules, leading to high uniformity and strength in multiple directions, which is particularly suitable for applications such as flooring. In contrast, processes such as extrusion and intrusion form the molecules mainly in the flow direction. This alignment results in higher tensile strength, impact resistance and shrinkage in the injected direction but can lead to anisotropic properties that limit strength and stiffness in other directions. Injection molding creates a "skin-core" effect (Hnatkova & Dvorak, 2016), with high molecular alignment near the walls, random orientation in the core and moderate overall uniformity. 3D Printing results in weaker, layer-dependent structures, limiting its use to decorative applications or the production of components with limited static or dynamic load.

In addition, production techniques each exhibit varying degrees of shaping flexibility, which significantly influences dimensions, level of detail, texture and overall aesthetics. These factors are crucial in determining the potential applications of the resulting components. For instance, injection molding provides exceptional precision and smooth finishes, making it well-suited for detailed components. However, it is less effective for producing larger parts. 3D printing offers design freedom allowing the creation of customized designs, but it is impractical for mass production due to its slow production speed and partly because of this significant higher production costs. In contrast, compression molding and intrusion molding are less precise, making these techniques more appropriate for simple, large-scale components where aesthetic or detailed features are secondary considerations. When dealing with uniform cross-sectional profiles, extrusion molding is ideal due to its efficiency. These considerations underscore the importance of aligning the production technique with the desired design and application requirements.

Also, the cost of manufacturing technologies is a crucial factor in the production of building components, as it directly affects the feasibility, scalability and affordability. Extrusion, intrusion and compression molding are cost-efficient for larger, simpler components. Injection molding has high start-up costs due to more expensive tooling but becomes economical with mass production. 3D printing is a relatively expensive manufacturing technology, making it less suitable when cost efficiency is a critical consideration.

Production techniques play a major role in determining the application possibilities of the final building product derived from the chosen recycled material. The combination of production technique and material (or material composite) is therefore critical when deciding where and how the building component can be used within the structure. Additives that enhance specific properties, such as fire resistance or UV stability, can be incorporated either during the production of the semi-finished product (pressed pellets extruded and granulate) or in some cases directly during the component production process (e.g. injection molding and extrusion molding). This interplay between material, technique and property optimization ultimately shapes the functional and design potential of the building component.

## III. EVALUATING MATERIALS PERFORMANCE

To evaluate the technical, design, environmental and economic performance of PolyAl and mixed plastics in housing construction, a comprehensive set of parameters is defined. These parameters facilitate a structured assessment, including comparisons with traditional materials such as structural softwood (C24), structural steel (S235) and concrete (Portland cement). This approach identifies the feasibility, benefits and areas for optimization of recycled plastics in construction. Data for mixed plastics parameters is derived from the technical datasheets of GovaPlast and Lankhorst, while data for PolyAl is based on the datasheet and insights provided by Recon Polymers. When direct data is unavailable, estimations are informed by the properties of polyolefins. Detailed parameter explanations and methodologies are in Appendix 4, with the complete dataset in Appendix 5.

### 3.1. Technical Performance

Based on the technical parameters found, PolyAl and mixed plastics can be alternatives to traditional materials like wood, steel and concrete, particularly in non-structural and semi-structural applications. They are most comparable to wood due to their similar tensile strength and lightweight nature, making them viable options for less critical load-bearing components such as interior partitions, cladding, decorative elements and doors or window frames. Their moisture resistance and durability further enhance their suitability as wood replacements. However, both materials lack the necessary strength to replace concrete or steel in heavy load-bearing applications, like beams and structural columns. They could still be used in non-structural concrete applications where high strength is not critical, but durability and weather resistance are of relevance. PolyAl and mixed plastics also offer advantages in thermal performance, being better than steel and concrete and comparable to wood. The fire resistance can be optimized by adding specific additives during production, as demonstrated by GovaPlast's B2-rated mixed plastics products. Their lightweight nature simplifies handling and installation, and while they are not suitable for high-strength applications, they show great potential in a range of building components where lower strength and moisture resistance are the primary demands. Further research is needed to explore reinforcement options to improve strength and stiffness.

### 3.2. Sustainable Performance

PolyAl and mixed plastics demonstrate high mass balance efficiency due to their complete recyclability, enabling efficient resource use and reducing reliance on virgin materials. Compared to traditional materials like concrete and steel, they offer significant sustainability advantages, as steel recycling is energy-intensive, and concrete has limited recyclability. Their recyclability makes them interesting for temporary structures, which can be dismantled and reused, minimizing waste. As KPMG Advisory N.V. (2023) states, "The longer you can prevent a product from being converted into $CO_2$, the better. Therefore, plastic-to-plastic will take precedence over waste-to-fuel applications." This highlights the priority of extending the lifespan of plastics by recycling, aligning with circular economy principles. While producing virgin plastic has a higher carbon footprint than wood, the impact of plastics is mitigated by efficient recycling, extending their functional lifespan. In contrast, wood degrades faster, often releasing carbon dioxide sooner. Increased use of recycled plastics over wood can also reduce deforestation, further supporting sustainability goals. It is important to bear in mind that in most cases the properties of recycled plastics will change during additional recycling steps. Therefore, it is of significant relevance to establish a strategy in advance to maintain the properties during the recycling cycle.

### 3.3. Design Performance

PolyAl and mixed plastics provide significant design flexibility, accommodating diverse production needs and applications. PolyAl excels in intricate designs, complex shapes and advanced finishes, offering a broader range of textures and colors. In contrast, mixed plastics are better suited for larger, simpler shapes, but tend to have coarser textures and darker colors, which can present aesthetic limitations in preferences. Both materials are versatile in processing, allowing cutting, drilling, painting and even welding. These qualities make them quite suitable for producing modular building components that support easy (dis)assembly. However, structural load-bearing capacity remains a major limitation, emphasizing the need for further innovation and development, including the use of additives.

### 3.4. Economic Performance

PolyAl and mixed plastics, represent a potential but underutilized resource in the construction sector. While the global problem of plastic waste highlights the urgent need for sustainable solutions, the limited applications for these high-potential recycled materials in construction require, based on certified components, further exploration to demonstrate applicability.

Moreover, the production processes for plastic materials offer significant efficiency advantages, particularly in terms of design flexibility. Unlike traditional materials such as wood, plastic processing typically requires minimal additional treatment following the extraction of raw materials, thereby further enhancing its cost and production efficiency.

## IV. Material Applications in Housing Design and Construction

PolyAl and mixed plastics, represent a potential but underutilized resource in the construction sector. While the global problem of plastic waste highlights the urgent need for sustainable solutions, the limited applications for these high-quality recycled materials in construction require further exploration and demonstrated applicability based on certified components.

Recycled plastics are naturally flexible, lightweight and resistant to moisture and rot, making them advantageous for specific building applications. However, their current structural properties, such as tensile and compressive strength, are insufficient for use as primary load-bearing elements in buildings. Despite this challenge, several strategies can improve the performance of these recycled plastics in construction:

1. **Composite Material Design based on reusable materials**: For example, adding fibers - such as natural and/or glass fiber, preferably recycled glass fibers - to the plastic matrix can significantly improve tensile strength and deformation resistance. Endless Composites reuses glass fiber from technically written-off wind turbines and boat hulls to reinforce plastic materials in applications (Endless Composites, n.d.). Salazar et al. (2013) highlight the significant potential of developing composite materials reinforced with natural fibers. Prototypes of these materials, created using various production techniques and fiber-reinforced composites blended with PolyAl and other polymers, show promise as alternatives to wood-based products across multiple industries.

2. **Interlocking and / or Integrated reinforced systems**: Designing components with interlocking features, similar to Lego blocks and systems, ensures even load distribution and can eliminate the need for mortar. Creating geometrically reinforcing patterns (e.g., cross-bracing or honeycomb structures) within the plastic blocks can improve their load-bearing capabilities. Block Solutions' interlocking systems are an example of how design innovation can improve stability (see Appendix Case Study 1G).

3. **High-Density Compression**: Using compression molding to manufacture high-density blocks increases their compactness and strength, making them suitable for more strength demanding applications.

4. **Metal Reinforcements**: Embedding steel rods, tubes or meshes into recycled plastic components, such as blocks, significantly improves tensile and compressive strength. This enables their use in structural frameworks capable of supporting heavier loads. ByBlocks demonstrate how reinforced recycled plastic can be utilized in modular building systems (see Appendix Case Study 1H).

While products from companies such as Govaplast, SavePlastics and Lankhorst demonstrate the utility of recycled plastics in outdoor applications like furniture and industrial infrastructure, their adoption in interior spaces remains limited. Usually due to the lack of fine finishes, textures and colors associated with materials common for use indoors like wood, stone or ceramics. Improved production technologies could overcome these barriers by producing higher-quality materials with enhanced finishes, fire resistance and insulation properties. Greater collaboration between recyclers, material scientists, architects and designers are critical to fostering awareness and encouraging adoption of recycled plastic materials across a broader range of construction applications. By addressing these challenges and leveraging innovative design strategies, recycled plastics can transition from a niche material to a cornerstone of sustainable housing construction.

## V. CONCLUSIONS

Recycled plastics, such as PolyAl and mixed plastics, show exceptional versatility thanks to their inherent properties and a wide range of available production techniques. This versatility highlights their potential for innovative applications in the built environment. Developments and innovations in production technologies and the addition of additives can extend their use to widely accepted interior applications, with enhanced qualities such as improved finish, fire resistance and insulation properties.

However, a major limitation of recycled plastics is their relatively low strength and stiffness, which limits their use in load-bearing applications. To address this, several strategies can be applied, such as reinforcing recycled plastics with natural or glass fibers and/or incorporating metal reinforcements. These options can significantly improve the mechanical properties of recycled plastics, allowing them to be used in more demanding applications. Optimized production techniques such as compression molding and construction strategies with interlocking systems as an example can increase material performance and optimize structural integrity by improving force distribution.

Despite the flexibility in shapes and applications offered by recycled plastics, aesthetic acceptance remains a challenge. A cultural shift towards appreciating the unique aesthetics of recycled materials, combined with innovative manipulation techniques such as advanced printing technologies and/or specific post-processing methods, could help bridge this gap. The choice of production techniques, such as extrusion molding for continuous profiles, injection molding for detailed parts and compression molding for strong, cost-effective components, plays a crucial role in determining the suitability of recycled plastic parts for different building applications.

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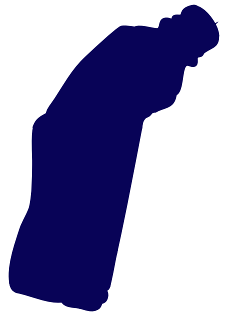
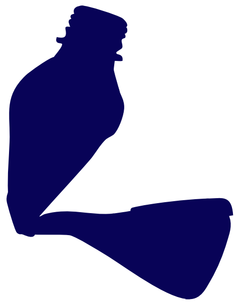




# appendix

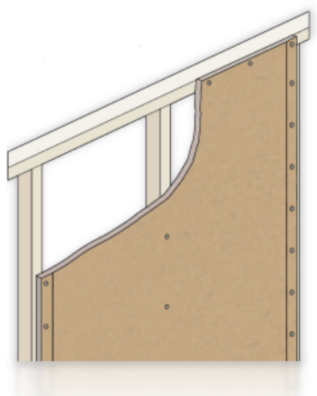
personal information
name: Nadine Nossbaum
student number: 4659716

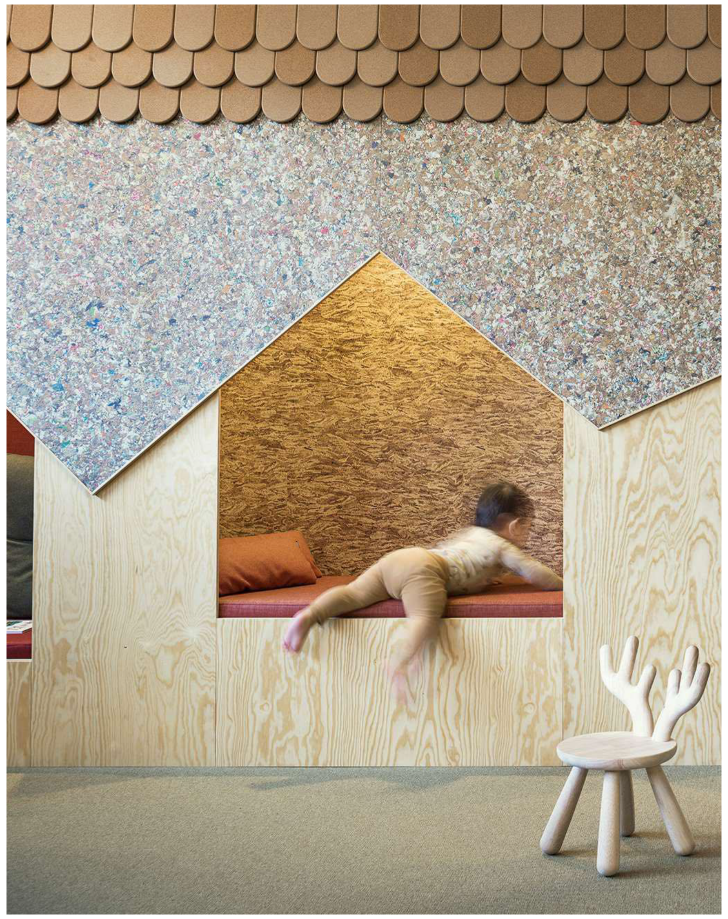
architectural engineering studio
design tutor: Dafne Swank
research tutor: Jos de Krieger
building technology tutor: Stephan Verkuijlen

focus
context: TU Delft campus
technology: make
design program: modular student housing

# appendix 1: case study analysis

# appendix 1A: case study analysis
# Recoma





**general product information**

| | |
|---|---|
| **Location** | Sweden |
| **Recycled Material** | PolyAl + paper fiber |
| **Waste Resource** | beverage cartons |
| **Product Form** | boards |
| **Production Technique** | compression molding |
| **Size** | min. 300 x 2400 x 8 mm<br>max. 1200 x 2800 x 15 mm |
| **Color** | brown / multicolored |
| **Texture** | laminated / smooth |
| **Recyclable** | yes 100% |

**specific product information**

| | |
|---|---|
| **Costs** | cheap technology, same price OSB / plywood |
| **Carbon Footprint** | 85-90% lower $CO_2$ emissions than alternatives (-10,58 Kg $CO_2e$ / $M_2$) |
| **Fire Resistance** | Class E Of D - S1, D1 |
| **Water Resistant** | no, needs water resistant treatment |
| **Key Considerations** | superior thermal and acoustic insulation |

**building product potential**

| | |
|---|---|
| **Material Replacement** | OSB / (ply)wood / plaster panel |
| **Possible Application** | • furniture and cabinetry<br>• roofing<br>• wall cladding and partition<br>• floor underlayment |
| **Assembly Strategy** | drilling, sawing, cutting, screwing, nailing, stapling, glueing, sealing |
| **Finishing Options** | painting, plastering, tiling |

Recoma is a Swedish company that focuses on sustainability in the construction industry by producing high-quality building boards from 100% recycled drinking carton packaging (PolyAl + paper fibre). Their innovative process involves upcycling waste materials that are traditionally difficult to recycle, creating a fully circular product.

The production process uses no water, additives or chemicals and generates no waste. The composite material is dried, sterilised, shredded and pressed at high temperatures into durable, lightweight and recyclable boards with excellent insulating properties. These boards are versatile, suitable to replace traditional wooden or plaster panels and can be painted, tiled or treated in the same way. Recoma's process reduces CO2 emissions by up to 90% compared to conventional materials.

Their products exemplify the principles of the circular economy, turning waste that would otherwise be incinerated into valuable, low-carbon building materials, contributing significantly to sustainable building practices.

**sources**
https://www.recoma.com/
https://cdn.prod.website-files.com/63c50bc07d33ed9d18aa8a88/66bd93e1525c0937e7f97f6f_RECOMA%20Technical%20Datasheet%5BEng%5D.pdf

# appendix 1B: case study analysis
# Ecopeal - PolyAl board and roof

**general product information**

| | |
|---|---|
| **Location** | Malaysia |
| **Recycled Material** | PolyAl |
| **Waste Resource** | beverage cartons |
| **Product Form** | (corrugated) board / sheet |
| **Production Technique** | compression molding |
| **Size** | 1041 x 2743 x 5 mm (corrugated)<br>1219 x 2438 x 5 mm (flat) |
| **Color** | metallic grey |
| **Texture** | composite |
| **Recyclable** | yes 100% |

**specific product information**

| | |
|---|---|
| **Costs** | cheap technology |
| **Water Resistant** | yes |
| **Heat Resistant** | yes |

**building product potential**

| | |
|---|---|
| **Material Replacement** | OSB / (ply)wood / plaster panel / plastics |
| **Possible Application** | • furniture and cabinetry<br>• roofing<br>• wall cladding and partition<br>• floor finishing |
| **Assembly Strategy** | drilling, sawing, screwing, nailing, glueing, sealing |

Ecopeal is a pioneering company in circular construction, dedicated to transforming waste into innovative building materials. They specialize in recycling PolyAl into high-performance, sustainable building products. By upcycling these materials, Ecopeal reduces environmental waste while offering eco-friendly alternatives to traditional building materials, such as wood.

Ecopeal's manufacturing process involves compression molding, transforming PolyAl into versatile products like durable panels. Their solutions actively support the circular economy by diverting non-biodegradable waste from landfills and ensuring these materials are continuously reused in construction applications.

The company's approach highlights the transformative potential of waste-to-resource innovation in reshaping the construction industry and advancing sustainable building practices.

**sources**
https://www.archimat.io/ecopeal-reshaping-the-construction-industry-with-circular-building-materials/

# appendix 1C: case study analysis
# Save Plastics / Save Cabin


Plastic Beach House


Save Home

**general product information**

**Location** Arnhem, Netherlands
**Recycled Material** mixed plastics
**Waste Resource** DKR350
**Product Form** (flexible) facade panels / beams / planks
**Production Technique** extrusion molding, intrusion molding
**Size** depends on product, customizable
- **ex. beam** 80-160 x 160-240 x 1500 - 3000mm

**Color** black / grey / brown
**Texture** slightly rough / wood-like
**Recyclable** yes 100%

**specific product information**

**Costs** cheap technology, low maintenance cost
**Technical Durability** > 40 jaar
**Temperature Resistance** -18°C to +50°C
**Water Resistant** yes
**UV Resistant** yes
**Weather Resistant** yes
**Key Considerations** easy to process, low maintenance, no cracking, rotting or splintering

**building product potential**

**Material Replacement** wood
**Possible Application**
- finishing (facades)
- foundation
- posts / planks / beams
- flooring

**Assembly Strategy** drilling, sawing, planing, screwing, nailing, stapling

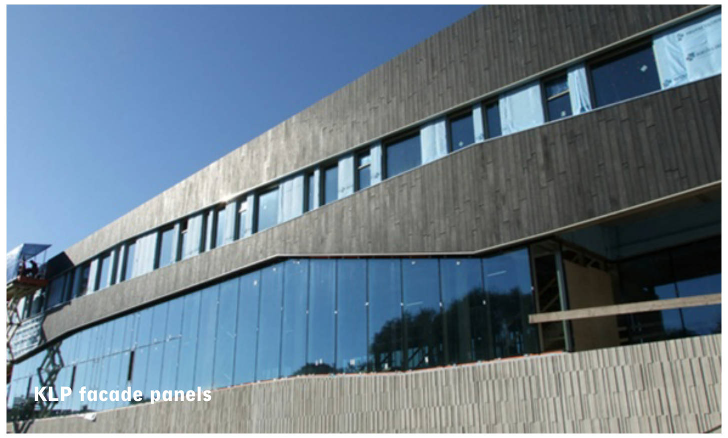
Save Plastics and its partner initiative Save Cabin exemplify the circular potential of recycled plastic materials in sustainable construction. Save Plastics reuses hard-to-recycle low-quality mixed plastic waste into sustainable products for infrastructure, landscaping and housing. Their materials are rot-resistant, shatterproof and maintenance-free, offering an environmentally friendly alternative to traditional wood.

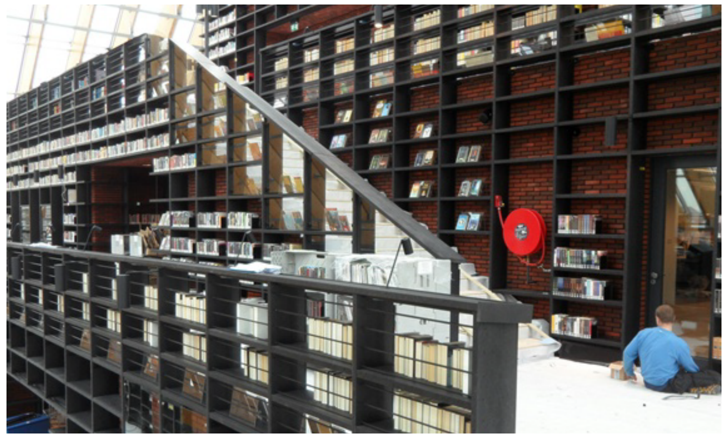
Save Cabin extends this approach to housing, creating relocatable, self-sufficient tiny homes and other structures from recycled mixed plastics. These projects, such as tiny houses and **Plastic Beach House**, transform thousands of pounds of mixed plastic waste into modern, flexible and environmentally conscious living spaces.

Together, these initiatives highlight the scalability of plastic recycling in addressing environmental and housing challenges while promoting a regional circular economy.


**sources**
https://saveplastics.nl
https://savecabin.nl
https://saveplastics.nl/wp-content/uploads/2023/02/leveringsprogramma-2022-2023.pdf
https://saveplastics.nl/product/kunststof-balken-2/


# appendix 1D: case study analysis
# Lankhorst


KLP facade panels



**general product information**

**Location** Sneek, Netherlands
**Recycled Material** mixed plastics
**Waste Resource** DKR350
**Product Form** facade panels / foundation / interior
**Production Technique** extrusion molding, intrusion molding, injection molding
**Size (facade panel maximum)** 138 - 198 x 2687 x 30 mm
**Color** anthracite-black, other colors on request
**Texture** slightly rough / wood-like
**Recyclable** yes 100%

**specific product information**

**Costs** cheap technology
**Technical Durability** > 50 years
**Fire Resistance** Class B
**Water Resistant** yes
**UV Resistant** yes
**Weather Resistant** yes
**Key Considerations** easy to process, maintenance free, no rotting or splintering

**building product potential**

**Material Replacement** wood / concrete
**Possible Application**
- furniture and cabinetry
- finishing (facades)
- foundation
- posts / planks / beams
- fencing
- flooring

**Assembly Strategy** drilling, sawing, planing, screwing, nailing, stapling

Lankhorst Recycling is a Dutch company that specializes in recycling mixed plastic waste, with a particular focus on converting non-sortable mixed plastics (such as DKR350) into durable and sustainable building materials. Through an extrusion process, they produce robust products such as plastic profiles, planks and structural components for various applications, including outdoor furniture, decking and infrastructure.

Their main product, **KLP** recycled plastic, is known for its long life, weather resistance and low maintenance requirements. Lankhorst uses a closed-loop system that ensures that post-consumer and industrial plastic waste is efficiently reused in high-quality products, in line with the principles of the circular economy. Their manufacturing process is designed to minimize environmental impact while providing materials that are both sustainable and functional, encouraging the use of recycled plastics in construction and infrastructure projects.


**sources**
https://www.lankhorst-recycling.com/files/0/0/7/8/TECHNICAL%20BROCHURE%20MARCH%202020%20-%20rev7.pdf
https://www.lankhorst-recycling.com/nl
https://www.lankhorst-recycling.com/files/0/4/7/7/KLP%C2%AE%20Facade%20Panels.pdf

# appendix 1E: case study analysis
# Aectual

| general product information | |
|---|---|
| **Location** | Netherlands |
| **Recycled Material** | PolyAl |
| **Waste Resource** | beverage cartons |
| **Product Form** | interior products / panels / facades |
| **Production Technique** | 3d printing |
| **Size** | maximum robot reach 3.2 meters<br>on a track of 9 meters<br>±170m³ printing volume |
| **Color** | any PMS / RAL / NCS color / grey - black<br>except: white / yellow |
| **Texture** | matte solid-colored / slightly rough |
| **Recyclable** | yes 100% |

| specific product information | |
|---|---|
| **Costs** | expensive technology |
| **Accoustic Performance** | possibilities within design |
| **Fire Resistant** | adding additives |

| building product potential | |
|---|---|
| **Material Replacement** | general 3d printed plastics / ceramics |
| **Possible Application** | interior elements<br>building blocks / bricks<br>panels<br>facade (elements) |
| **Assembly Strategy** | drilling, screwing, nailing |

Aectual is an innovative Dutch company that specializes in sustainable architectural solutions by integrating circular design principles with advanced 3D printing technology. Their mission is to revolutionize the building industry by creating customizable, high-quality building components that minimize waste and environmental impact. Aectual uses recycled and bio-based materials, such as PolyAl and other sustainable composites, to produce products ranging from flooring systems to façade elements and furniture.

Their manufacturing process includes large-scale robotic 3D printing, which enables precise, material-efficient production while supporting the reuse of raw materials in a closed-loop system. Aectual's approach aligns with the goals of circular building by using recycled materials, such as mixed plastics and polyal (polyethylene-aluminum), diverting waste streams from landfills and turning them into sustainable, aesthetically pleasing architectural products. The company's work exemplifies the potential for merging advanced technology and circular material flows to build a sustainable future.

**sources**

https://www.aectual.com/
https://blog.aectual.com/Aectual_Tetra_Pak

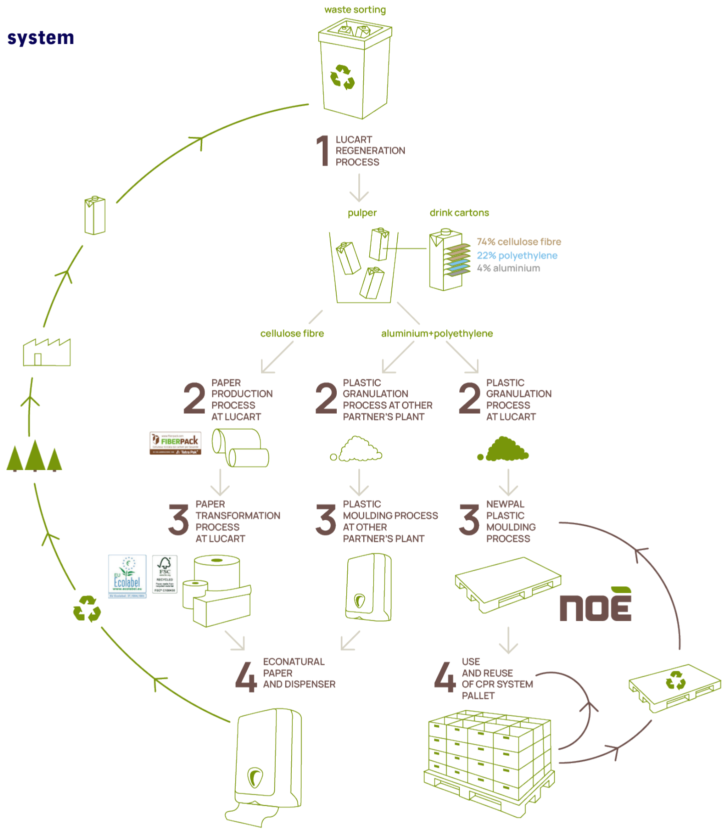
# appendix 1F: case study analysis
# Newpal / Lucart - PolyAl pallet

| general product information | |
|---|---|
| **Location** | Italy |
| **Recycled Material** | PolyAl |
| **Waste Resource** | beverage cartons |
| **Product Form** | pallets |
| **Production Technique** | injection molding |
| **Size** | 800x1200x150 mm |
| **Color** | brown |
| **Texture** | polished / composite |
| **Recyclable** | yes 100% |

| specific product information | |
|---|---|
| **Technical Durability** | much more durable than wood |
| **Water Resistant** | yes |
| **Key Considerations** | no rotting, rust or splintering |

| building product potential | |
|---|---|
| **Material Replacement** | wood |
| **Possible Application** | bricks / blocks<br>structural parts |
| **Assembly Strategy** | click system design possible |

**system**




**sources**

https://www.tetrapak.com/insights/cases-articles/polyal-based-pallet-launch-in-italy#:~:text=The%20non%2Dfibre%20component%20of,content%20in%20aseptic%20carton%20packages.
https://www.newpal.it/en/the-noe-pallet/
https://www.newpal.it/wp-content/uploads/2023/07/CPR_Rev3_Scheda-informativa-Pallet-Plastica-Riciclata-PR12.pdf

# appendix 1G: case study analysis
# Block Solutions

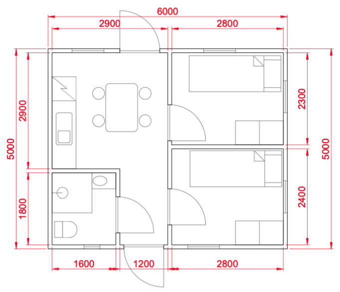
**general product information**

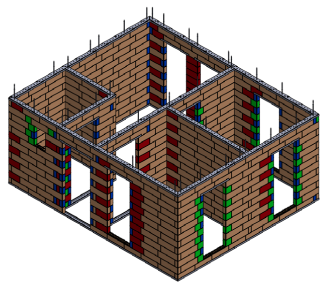
| | |
|---|---|
| **Location** | Finland |
| **Recycled Material** | biocomposite mix from recycled polypropylene and organic fibers from traceable origins |
| **Product Form** | block |
| **Production Technique** | compression molding |
| **Size** | 100/200/400/800x200x200mm |
| **Color** | different colours possible |
| **Texture** | smooth / composite |
| **Recyclable** | yes |

**specific product information**

| | |
|---|---|
| **Fire Resistance** | overed with gypsum board / concrete |
| **Reinforcement** | composite / structure / with threaded rod |

**model house system 40m²**

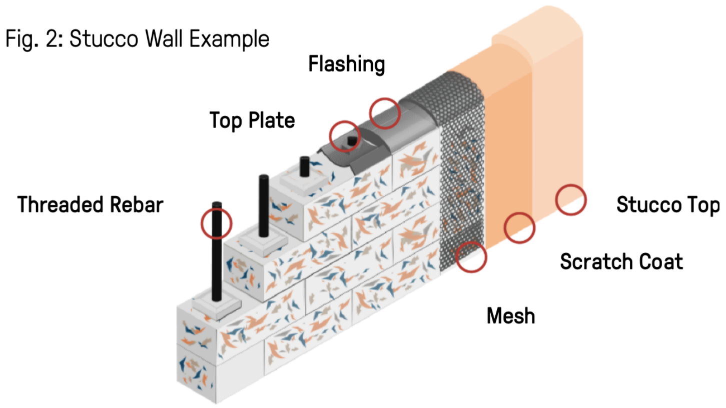


**sources**
https://www.block-solutions.com

# appendix 1H: case study analysis
# ByFusion - ByBlock

Fig. 2: Stucco Wall Example



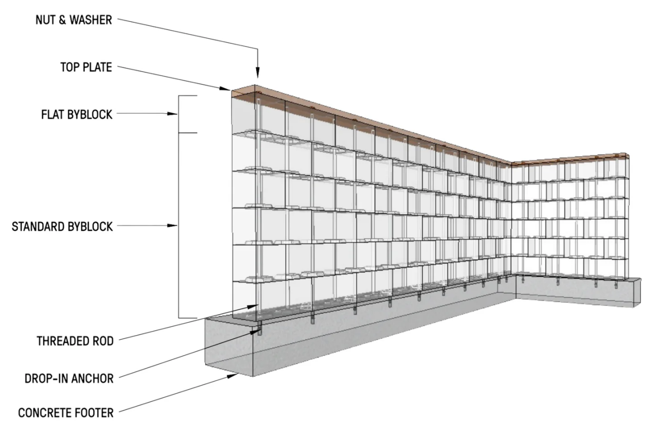

**general product information**

| | |
|---|---|
| **Location** | USA |
| **Recycled Material** | 100% non-recyclable plastic content |
| **Waste Resource** | plastic waste |
| **Product Form** | block |
| **Production Technique** | compression molding |
| **Size** | 394x197x227mm |
| **Color** | vary due to nature of material |
| **Texture** | rough / composite |
| **Recyclability** | yes, not zero-waste |

**specific product information**

| | |
|---|---|
| **Fire Resistance** | adding additives |
| **Water Resistant** | yes |
| **Reinforcement** | with threaded rod |

**system**



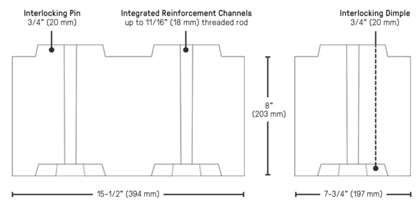




*Fig.1 BBK-011 Standard ByBlock dimensions and features*

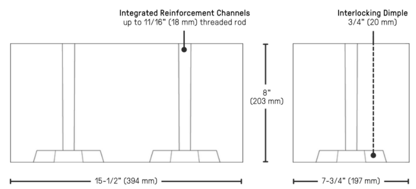
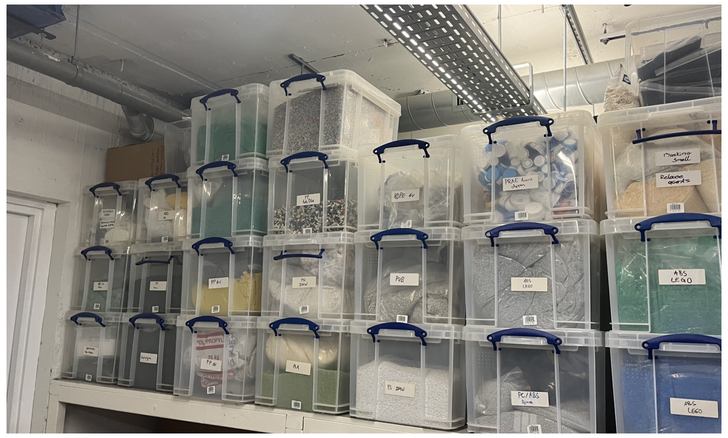



*Fig.2 BBK-012 Flat ByBlock dimensions and features*

**sources**
https://byfusion.com/pages/building-with-byblock
https://www.tenderstream.com/assets/tenders/2019/201902/1550577647_8845_byfusion2.pdf
https://cdn.shopify.com/s/files/1/0614/1781/6276/files/ByBlock_Product_Data_Sheet_v2.1.pdf?v=1714613323

# appendix 2: field research report

# appendix 2A: field research report
# Better Future Factory





**company information**

**Company / Organization** Better Future Factory
**Location** Rotterdam, The Netherlands
**Field of Expertise** Sustainable Plastics R&D

"Our expertise lies in accelerating sustainable product development, ensuring your products stay relevant today and resilient for the challenges of tomorrow."

**Date of Visit** 26 November 2024
**Purpose of Visit** Talking about the the first project approaches, and receiving feedback, tips and , great expertise insights into the material. New things that i did not know to take into account and more companies to research.

**summary of findings**

- This company specializes in the transformation of various recycled plastic materials into products, as well as interior and furniture finishes.
- When designing with materials derived from mixed plastics, it is essential to consider the material's thermal expansion properties and the directional variability of expansion. These factors can pose challenges under varying temperature conditions.
- Microplastics, when managed and processed appropriately, present less of a problem than is often portrayed in public discourse.
- Noteworthy companies in the field include Lankhorst, SavePlastics, and Govaplast, which are valuable references for further exploration in this domain.
- The incorporation of composite materials such as glass fiber or talc into recycled plastics offers significant reinforcement and enhances material performance.

**references**
**https://betterfuturefactory.com/**

BETTER FUTURE FACTORY

# appendix 2B: field research report
# plastichuisje.nl / Clean2Anywhere

**company information**

**Company / Organization** Clean 2 Anywhere
**Location** Hoorn, The Netherlands
**Field of Expertise** Building ships and tiny housing with from recycled mixed plastics materials
**Types of Plastic** recycled plastic materials

**Date of Visit** 20 December 2024
**Purpose of Visit** Showing me their projects and the tools they use to build their ships, while discussing the pros and cons of working with recycled plastic materials.

**summary of findings**

- In addition to manufacturing ships, the company is taking steps in the production of tiny housing solutions.
- The company is currently exploring suitable composites for the fabrication of masts.
- Their materials are sourced from Lankhorst and exhibit several advantages in terms of machinability and functionality. However, challenges remain regarding strength, stiffness, and creep resistance.

**references**
**https://www.clean2a.nl/**
**https://plastichuisje.nl/**

C2A
CLEAN 2 ANYWHERE

# appendix 2C: field research report
# ReconPolymers


**company information**

| | |
|---|---|
| **Company / Organization** | Recon Polymers |
| **Location** | Roosendaal, The Netherlands |
| **Field of Expertise** | Production of pressed pellets from PolyAl creating a new resource. |
| **Types of Plastic** | PolyAl |
| **Date of Visit** | 13 December 2024 |
| **Purpose of Visit** | Talking about the the first project approaches, and receiving feedback, tips and insights into both PolyAl and mixed plastics material. |

**summary of findings**

- The company identifies significant potential in the application of recycled PolyAl in construction, also when reinforced into composite materials.
- DKR350 as residual plastic stream, is anticipated to become processable in the future with modifications to the company's existing technological framework.
- The utilization of pressed pellet technology enables compatibility with all possible discussed further production techniques.

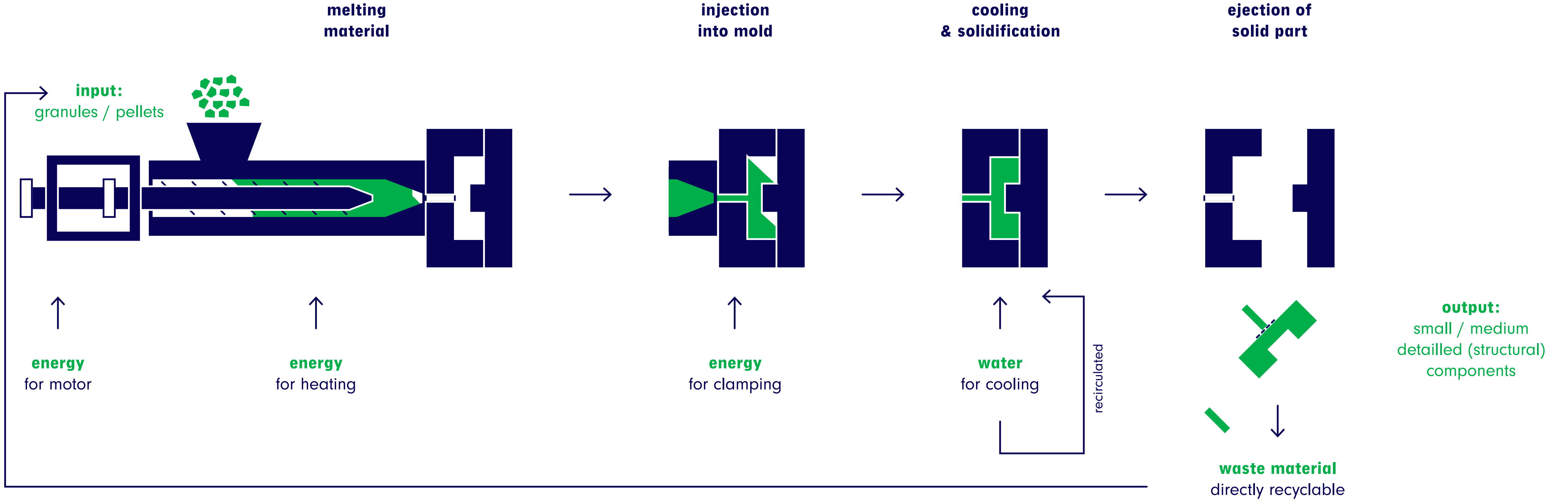
**references**
**https://reconpolymers.com/**

recon polymers

a new raw material technology

# appendix 3: production technique representation

# appendix 3A: production technique representation
# injection molding




**advantages**
- **high precision**: ideal for complex, detailed components
- **scalability**: highly efficient for mass production
- **surface finish**: produces smooth, finished surfaces
- **recycled material use**: works with various recycled plastics

**disadvantages**
- **initial cost**: mold-making cost can be high
- **limited size**: not suitable for very large components

**costs**
**low**: when mass produced

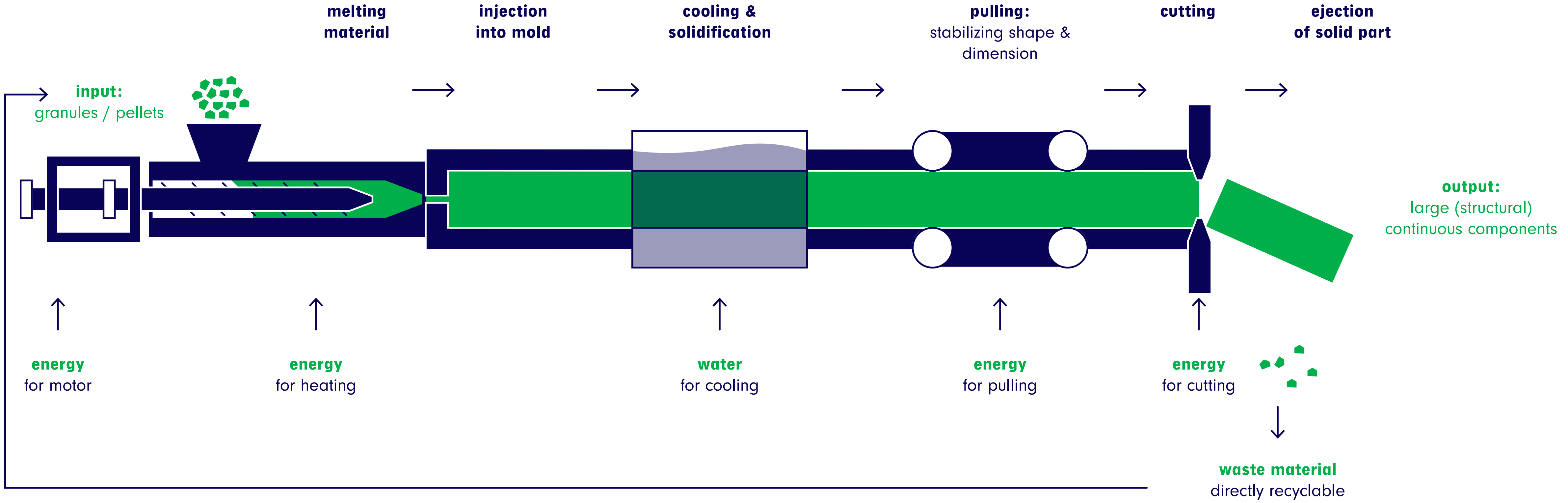
**energy efficiency**
**moderate**: mostly heating

**water use**
**low**: can be recirculated

**$CO_2$ footprint**
primarily from electricity if not renewable

**molecular distribution**
high alignment near walls, random in core and moderate uniformity (skin-core effect)
> **strong surface for fine and complex components**

# appendix 3B: production technique representation
# extrusion molding




**advantages**
- **continuous production**: ideal for long, uniform components (pipes, profiles, beams, sheets)
- **shape possibilities**: not only solid but also hollow shapes possible
- **recycled material use**: handles inconsistent recycled plastics well
- **high efficiency**: minimal waste during production

**disadvantages**
- **limited shape flexibility**: only produces uniform cross-sectional profiles

**costs**
**very low**: for continuous (simple) components

**energy efficiency**
**high**: due to continuous operation and low waste

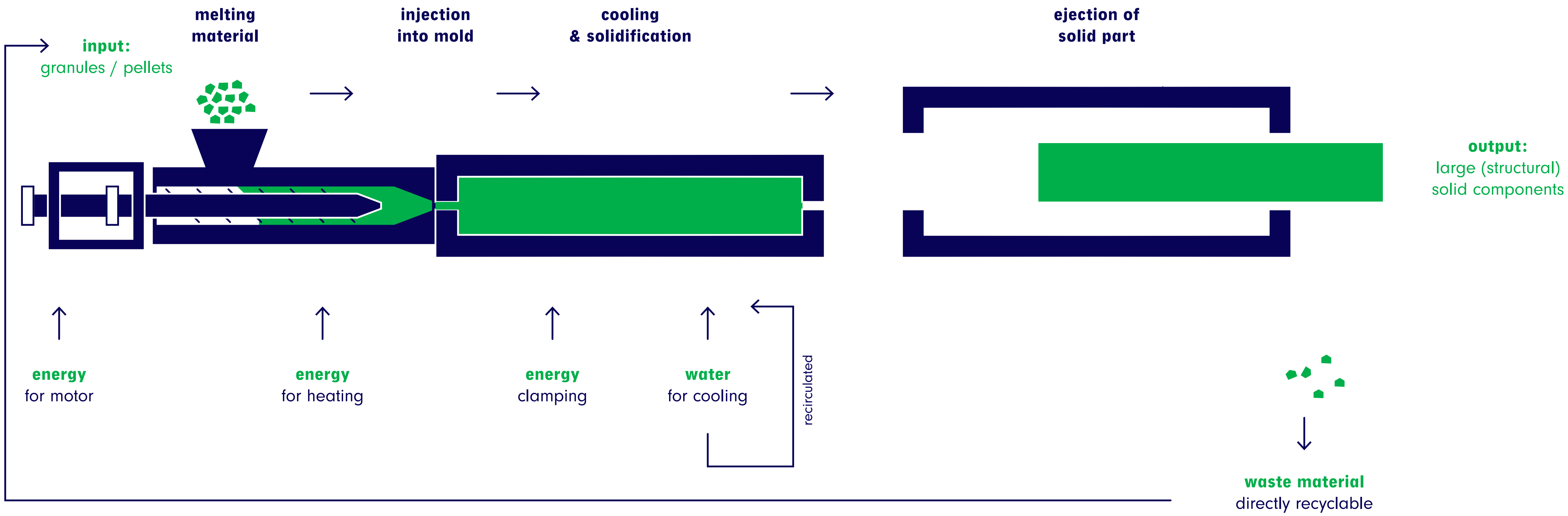
**water use**
**high**: recirculation systems minimize loss

**$CO_2$ footprint**
efficient, continuous production reduces overall impact, especially for large-scale production of simple components

**molecular distribution**
high alignment and uniformity
> **high tensile strength in extrusion direction**


**sources**
https://www.madearia.com/blog/the-difference-between-injection-molding-and-extrusion-molding/
https://hitopindustrial.com/difference-between-injection-molding-and-extrusion/
https://zetarmold.com/reduce-energy-consumption-injection-molding/
https://www.qenos.com/internet/home.nsf/(LUImages)/nwWP%20Orientation%20in%20Injection%20Moulding/$File/WP%20Orientation%20in%20injection%20moulding.pdf
https://www.mdpi.com/2073-4360/15/20/4046

# appendix 3C: production technique representation
## intrusion molding




**advantages**
- **large components:** suitable for producing large components (panels, beams)
- **recycled material use**: handles inconsistent recycled plastics well
- **cost efficiency**: lower mold cost compared to injection molding

**disadvantages**
- **precision limits**: less accurate for detailed or complex shapes
- **surface finish**: may require post-processing for aesthetic applications
- **cycle time**: slower than injection molding

**costs**
**low**: low mold costs, large simple components

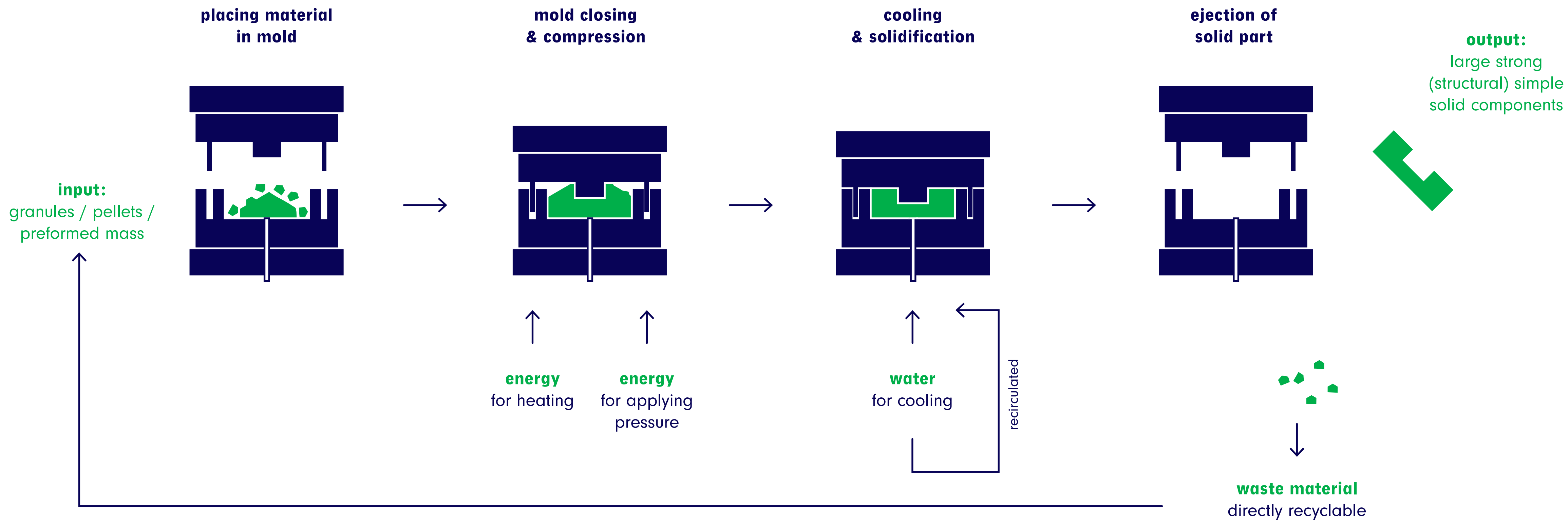
**energy efficiency**
**high**: simple, large components and low waste

**water use**
**low**: can be recirculated

**$CO_2$ footprint**
primarily from electricity if not renewable
less energy-intensive molds than injection molding

**molecular distribution**
minimal alignment (isotropic) and high uniformity
> **dense and solid components, where molecular orientation is not critical and strength needs to be evenly distributed**

# appendix 3D: production technique representation
## compression molding




**advantages**
- **large, simple components**: great for thick panels or tiles
- **high strength**: produces robust components due to uniform compression
- **recycled material use**: excellent for mixed or impure plastics

**disadvantages**
- **cycle time**: slower than injection or extrusion molding
- **detail limitations**: limited for complex designs

**costs**
**low**: simple components

**energy efficiency**
**moderate**: mostly heating and applying pressure

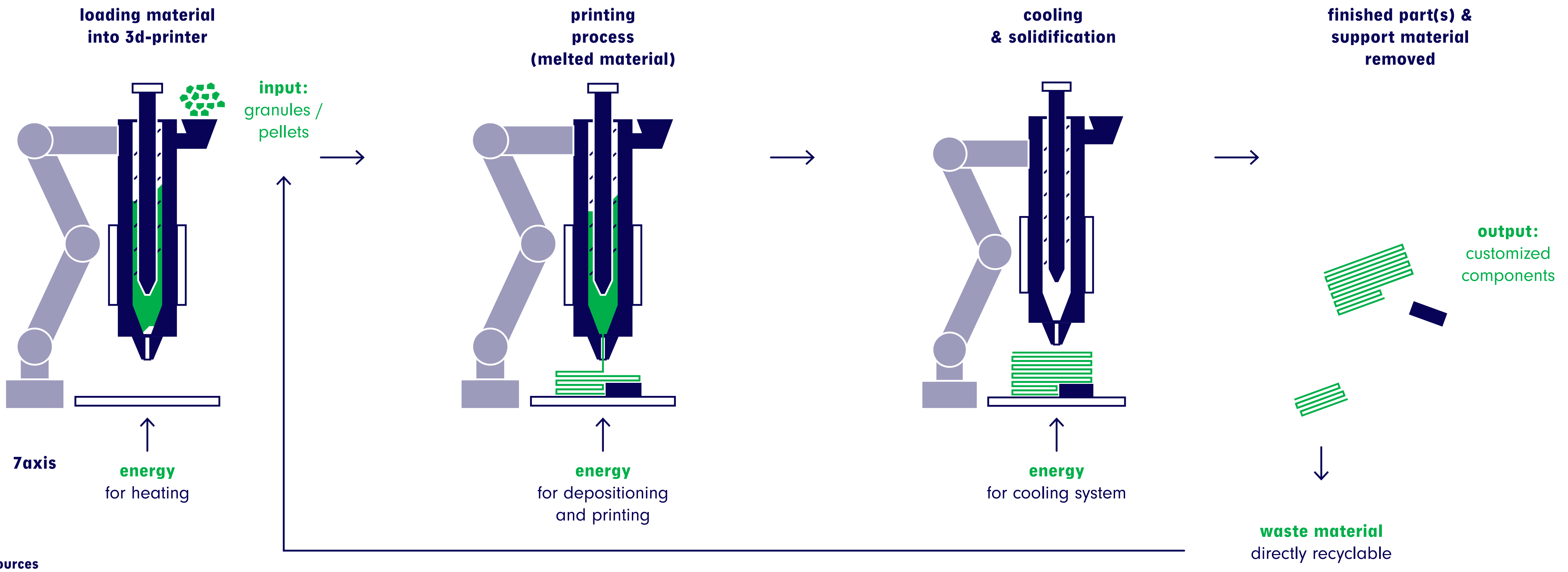
**water use**
**low**: can be recirculated

**$CO_2$ footprint**
primarily from electricity if not renewable

**molecular distribution**
random orientation (isotropic) and high uniformity
> **strong in multiple directions**

**sources**
https://www.youtube.com/watch?v=JYPnrPR6EpY
https://macrodynepress.com/compression-molding-101/
https://www.iqsdirectory.com/articles/rubber-molding/compression-molding.html

# appendix 3E: production technique representation
# 3d-printing - fused granular fabrication (FGF)




**sources**
https://blog.aectual.com/3d-printing-technology
https://www.mdpi.com/2504-477X/8/6/222
https://link.springer.com/article/10.1007/s40962-023-00989-9#Sec6

**advantages**
- **design freedom**: can produce highly complex and custom designs
- **small-scale production**: ideal for prototyping or custom elements
- **localized production**: no need for mass manufacturing infrastructure

**disadvantages**
- **slow speed**: not suitable for large-scale production
- **surface finish**: often requires post-processing for a smooth finish
- **recycled material use**: requires finely processed recycled pellets

**costs**
**high**: for large components, useful for small components or prototyping

**energy efficiency**
**low**: large-scale production is energy intensive

**water use**
**none**

**$CO_2$ footprint**
high for large components or when non-renewable electricity is used

**molecular distribution**
layer-based alignment and low uniformity
> **weak structures, decorative and lightweight components**

# appendix 4: parameter information

# appendix 4A: parameter information technical

| parameter | explanation | relevance | measurement |
|---|---|---|---|
| **Material Composition** | The chemical composition of the material, including its constituent polymers and potential composite materials. | Determines recyclability possibilities, compatibility with other materials, and ease of use and maintenance. | breakdown in percentage of different polymers and possible composite materials involved (e.g., polypropylene (PP), polyethylene (PE), Aluminum (Al)) |
| **Production Technique(s)** | The processes that can be used to produce desired components from the recycled plastic material. | The method impacts the final product's quality, precision, and production cost. It will determine the material's form, design possibilities, and suitability for specific applications. | identification of production process, including:<br>▪ extrusion molding<br>▪ injection molding<br>▪ compression molding<br>▪ intrusion molding<br>▪ 3D printing |
| **Density** | The mass of the material per unit volume. | Affects the weight of the material, which impacts structural applications, handling and transportation. | kilograms per cubic meter ($kg/m^3$) or megapascals (MPa) |
| **Tensile Strength** | Measures the maximum stress a material can withstand while being stretched without breaking. | Indicates how much load the material can withstand before breaking or being permanently deformed, critical for structural applications and durability. | Newtons per square millimeter ($N/mm^2$) or megapascals (MPa) |
| **Flexural Strength** | The material's ability to resist bending under load. | Essential for load-bearing applications, this determines how the material resists deformation under bending forces, vital for beams, panels, and structural components. | Newtons per square millimeter ($N/mm^2$) |
| **Impact Strength** | Reflects how well the material can absorb and dissipate energy from sudden forces or impacts without fracturing. | Important for safety in environments with a risk of accidental shock or vibration. | joules (J) or kilojoules per square meter ($kJ/m^2$) |
| **Elastic Modulus** | Measures the material's stiffness and ability to return to its original shape after deformation. | Reflects rigidity and stability in structural components. Determines suitability for frameworks and support elements requiring dimensional stability. | Newtons per square millimeter ($N/mm^2$) or gigapascals (MPa) |
| **Technical Durability** | Describes how long a material can maintain its performance and integrity under external factors such as weathering, UV exposure or wear. | Indicates the material's lifetime, especially for exterior applications like facades, roofs and foundations. | years |
| **Thermal Conductivity** | The material's ability to retain or resist heat, affects energy efficiency and comfort of the building | For wall, roof and window insulation. | λ-value in Watts per meter Kelvin (W/m·K) |
| **Fire Resistance** | Measures the ability of a material to resist ignition, limit flame spread and maintain structural integrity under fire conditions. | It ensures compliance with safety standards and limits fire risks. Critical to building safety, especially in structural elements, wall coverings and ceilings. | fire resistance classification EN 13501-1 (flammability, smoke production and flaming droplets) |
| **Moisture Resistance** | Defines a material's ability to resist water absorption, preventing degradation, mold growth or swelling. | Essential for applications in wet areas or exterior environments, such as facades and roofs. | low, medium, high |
| **Expansion and Contraction** | Refer to the material's dimensional changes due to temperature variations. | Important to ensure structural integrity and compatibility in applications with temperature fluctuations. It is important to design expansion joints or allow tolerances in applications with aligned materials to accommodate directional expansion/contraction. | coefficient of thermal expansion (CTE) in micrometers per meter per degree Celsius (mm/m·°C) |
| **Key Considerations** | Unique attributes or challenges specific to the material that may influence its suitability for particular applications, which can be critical for decision-making. | | |
| **Safety** | Identifies potential hazards associated with the material, such as toxic emissions, flammability, or chemical leaching. | Ensures material safety for users and environmental health. | Yes / No<br>and specific details of the safety risk |

# appendix 4B: parameter information design

| parameter | explanation | relevance | measurement |
|---|---|---|---|
| **(Production) Size** | Refers to the range of dimensions that can be achieved during the material manufacturing process. | Determines suitability for architectural elements and complex applications. | per material per production technique:<br>▪ Minimum: width × length × height (in mm)<br>▪ Maximum: width × length × height (in mm) |
| **Application Potential** | Adaptability to a wide range of architectural applications. | Discovers the potential to replace traditional materials and increase material utility by broadening its application range, allowing for design flexibility and multi-functionality. | list of architectural elements or forms the material is suited for<br>▪ Sheet / Board<br>▪ Block / Brick<br>▪ Interior Elements<br>▪ Exterior Elements (e.g. finishing)<br>▪ Structural Components (e.g. beams, columns, foundation)<br>▪ Insulation |
| **Formability** | The ease with which the material can be shaped by bending or molding it into different shapes. | Determines the ability to adapt to unique design needs and (more) complex geometries. | assessment of processes the material supports (molding, bending) and the required force or conditions (temperature) |
| **Aesthetic Flexibility** | The ability to customize the material for different architectural styles (available range of textures, colors, finishes). | Ensures that the material matches the aesthetic goals within the design vision of the material within the project. | available range of:<br>▪ Texture: smooth, rough, polished, composite, etc.<br>▪ Finishing: laminated, matte, gloss, semi-gloss, etc.<br>▪ Coloring: solid- / non solid-colored, range of customizable colors<br>▪ Printable: yes / no |
| **Fastening and Installation Possibilities** | The material's compatibility with different fastening systems and its (dis)assembly potential. | Affects the efficiency of modular construction, labor requirements and suitability for prefabricated building components. | identification of supported possibilities:<br>▪ Screws<br>▪ Adhesives<br>▪ Interlocking systems<br>▪ Etc. |
| **Possible Processing** | Takes into account the types of additional operations the material supports after initial production. | Determines how easily the material can be integrated into post-production workflows and how best to adapt it to the modular project needs. | identification of supported possibilities:<br>▪ Cutting<br>▪ Drilling<br>▪ Painting<br>▪ Surface treatment<br>▪ Etc. |
| **Modular (Dis)assembly Strategy** | Production Size, Formability, Fastening and Installation Possibilities and Sustainable Durability form the basis to decide if the material has good potential for a modular (Dis)assembly Strategy. | **Focus on**<br>**1. Production Size** and **Formability**: Identify whether the material supports modular dimensions and standard prefabricated systems<br>**2. Fastening and Installation Possibilities**: Assessment of whether the material can be easily assembled and disassembled and if time required is efficient | flexible - not fexible |

# appendix 4C: parameter information sustainability

| parameter | explanation | relevance | measurement |
|---|---|---|---|
| **Recyclability** | Measures the ability of a material to be recovered and reprocessed into new products. | Determines the environmental impact of the material at the end of its life cycle and the extent to which it reduces dependence on virgin raw materials. | percentage of material that is recyclable (0–100%) and the percentage of virgin recycled material added in production |
| **Carbon Footprint** | Accounts for the greenhouse gas emissions released during its (recycled) life cycle. | An important measure for assessing environmental impact and contribution to climate change. A lower carbon footprint indicates more sustainable material options. | kilograms of $CO_2$ equivalent (kg $CO_2e$) per kilogram (kg) |
| **Sustainable Durability** | Measures the ability of the material to maintain the function of the building component when it endures multiple (dis)assembly /replacement cycles, before the material needs to be recycled again because of significant degradation in structural or functional integrity. | Critical for modular construction and sustainable reuse. For plastics, includes microplastic formation and loss of properties after repeated cycles. | assessment of time cycle (technical durability years) |
| **Mass Balance Efficiency** | Reflects how efficiently resources are utilized in the production process, minimizing losses and maximizing the usable portion of raw materials. | Helps in evaluation by demonstrating the relative sustainability benefits of effective material recovery versus unusable reject. | in percentage (%) / low - high estimation<br>Mass Balance Efficiency = (Mass of Raw Material Input / Mass of Usable Product) × 100 |
| **Location of Manufacturing** | Whether the material can be manufactured onsite or requires offsite location facilities. Evaluates the distance from the material production to the application site, when offsite manufacturing. | Determines implications for transportation, prefabrication, and environmental impacts. Local production reduces transport energy and emissions, boosts local economies. | identification of possibility<br>▪ Onsite<br>▪ Offsite |
| **Material Replacement** | Assesses which traditional materials the recycled plastic material can substitute. | Demonstrates the comparative sustainability advantages, including lower embodied energy, waste reduction, and carbon footprint. | replaced materials (wood / concrete / steel) and their relative environmental savings |

# appendix 4D: parameter information economical

| parameter | explanation | relevance | measurement |
|---|---|---|---|
| **Material Costs** | The cost of obtaining the recycled plastic material in its raw form, market price and transport are taken into account. | Understanding raw material costs is crucial for assessing feasibility and competitiveness compared to conventional materials. | estimaton:<br>▪ Low<br>▪ Medium<br>▪ High |
| **Production Costs** | The costs incurred during the manufacturing and production phases (capital investments (CAPEX) and energy / labor / maintenance (OPEX)) | Identifying costs associated with processing recycled plastic into component helps evaluate scalability and overall economic feasibility within project. | estimaton:<br>▪ Low<br>▪ Medium<br>▪ High |
| **Gate Fee** | A charge levied on waste materials delivered to a recycling facility. | Identifythe cost-effectiveness of using recycled plastics compared to traditional building materials. | yes / no |
| **Overall Costs** | Taking material costs, production costs and any applicable gate fees into account. | Creating an estimated overview. | estimaton:<br>▪ Low<br>▪ Medium<br>▪ High |
| **$CO_2$-emission** | Reflecting the environmental costs of greenhouse gas emissions. | Considering $CO_2$ emissions as an economic parameter in the research can highlight the financial and environmental advantages of using recycled plastics over traditional building materials (especially in regions with carbon pricing policies). | estimaton:<br>▪ Low<br>▪ Medium<br>▪ High |

# appendix 5: parameter data

# appendix 5A: parameter data technical

| material | composition (-) | production technique (-) | density (kg/m$^3$) | tensile strength (N/mm$^2$) or (MPa) | flexural strength (N/mm$^2$) or (MPa) | impact strength (J) or (kJ/m$^2$) | elastic modulus (N/mm$^2$) or (MPa) | technical durability (yrs) | thermal conductivity (W/m·K) | fire resistance A1-E, s, d | moisture resistance (low - high) | expansion coefficient (mm/m/°C) | key considerations (-) | safety (yes/no) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PolyAl** | Polyethylene (PE): 82%<br>Polypropylene (PP): 7%<br>Aluminium (Al): 11% | 3D-Printing<br>Compression Molding<br>Injection Molding (small/medium/ large objects)<br>Extrusion Molding<br>Intrusion Molding | 1083 kg/m$^3$ | 13.3 Mpa | ~19 Mpa | 6.7 kJ/m$^2$ | 8380 Mpa | 50+ yrs | 0.22 (W/m·K) | unknown<br>depends on application<br>additives possible | high<br>non absorbing<br>water proof | 0.05 mm/m/°C<br>(estimated) | > Odur at higher production temperatures (>200°C)<br>> Molecule direction | yes, coming from food contacted sources and heavily washed, basic input material originating from mainly food contacted packaging, proof that it has already been used in building and construction |
| **Mixed Plastics (DKR350)** | Typical packaging (PE / PP / PS / PET): 90%<br>Impurities: 10% | Compression Molding<br>Injection Molding (large objects)<br>Extrusion Molding<br>Intrusion Molding | 960 kg/m$^3$ | 17.2 Mpa | 15.7 Mpa | 65.6 kJ/m$^2$ | 572 Mpa | 50+ yrs | 0.34 (W/m·K) | B2 | high<br>non absorbing<br>water proof | 0.109 mm/m/°C | > Molecule direction<br>> Difference and percentage in contamination<br>> Color is limited | yes, coming from food contacted sources and heavily washed, basic input material originating from mainly food contacted packaging, proof that it has already been used in building and construction |
| **compared to** | | | | | | | | | | | | | | |
| **Concrete (portland cement)** | Cement<br>Water<br>Sand<br>Aggregate<br>(Steel reinforcement) | Casting<br>Curing<br>Molding | ~2400 kg/m$^3$ | ~2–5 Mpa<br>depends on reinforcement | ~3.5–7 Mpa | <1 kJ/m$^2$ | ~30,000–40,000 MPa | 50+ yrs<br>with proper maintenance | ~1.4 W/m·K | high | high | low<br>cracking due to temperature fluctuations | > Heavy<br>> Labor-intensive installation<br>> Limited flexibility<br>> Requires curing time | yes |
| **Steel (S235)** | Iron (Fe)<br>Carbon (C)<br>Small amounts of alloying elements | Rolling<br>Forging<br>Casting / Molding<br>Welding | ~7850 kg/m$^3$ | ~400–550 MPa | ~400–550 MPa | 15-30 kJ/m$^2$ | ~200,000 MPa | 50+ yrs<br>depends on environmental exposure and treatment | ~50 W/m·K | low<br>requires fireproof coating to keep integrity | high<br>rusts without coating in wet environments | moderate<br>experiences significant expansion under heat, requires allowance in design | > Requires corrosion protection<br>> Heavy<br>> High precision in fabrication | yes |
| **Wood (C24)** | Softwood (spruce, pine or fir) | Cutting<br>Bonding (plywood) | ~400–600 kg/m$^3$ | ~7–10 MPa | ~24 MPa | 5-20 kJ/m$^2$ | ~10,000–12,000 MPa | 20–50 yrs<br>depends on wood treatment and maintenance | ~0.13 W/m·K | low<br>requires fire-retardant chemicals | low / moderate<br>if not treated | moderate | > Susceptible to rot<br>> Pests; treated wood is more durable but costly | yes |


**sources**

mixed plastics
https://www.lankhorst-recycling.com/files/0/4/7/7/KLP%C2%AE%20Facade%20Panels.pdf
https://www.lankhorst-recycling.com/files/0/0/7/8/TECHNICAL%20BROCHURE%20MARCH%202020%20-%20rev7.pdf
https://www.govaplast.com/wp-content/uploads/2016/08/technical_product_information_govaplast-2017.pdf
https://kidv.nl/media/publicaties/recycling_van_kunststofstromen_van_bedrijven.pdf?1.2.23)

polyal
technical data sheet Recon Polymers
https://www.plasticportal.eu/image/staticke/File/2023_Plastigram_rLDPE_TDS_eng.pdf
https://www.scribd.com/document/675390067/Poly-Al-Pro-Boards-with-a-purpose-flyer

concrete
https://www.engineeringtoolbox.com/concrete-properties-d_1223.html#:~:text=Properties%20of%20normal%20strength%20Portland%20cement%20concrete.&text=Compressive%20strength%20%3A%2020%20%2D%2040%20MPa,MPa%20(300%20%2D%20700%20psi)
https://www.joostdevree.nl/bouwkunde2/jpgb/beton_17_achtergrondkennis_beton_www_scheikundeinbedrijf_nl.pdf

wood
https://www.sleiderink.nl/kennisbank/de-sterkteklasse-van-hout#:~:text=Het%20betekent%20dat%20het%20hout,constructies%20zoals%20interieurafwerkingen%20en%20timmerwerk.&text=C24%20hout%20heeft%20een%20hogere,buigsterkte%20van%2024%20N%2Fmm².
https://www.dataholz.eu/fileadmin/dataholz/media/baustoffe/Datenblaetter_en/vh_en_01.pdf

steel
https://steelnavigator.ovako.com/steel-grades/s235/
https://eurocodeapplied.com/design/en1993/steel-design-properties

# appendix 5B: parameter data design

| material | production size (min.) WxLxH (mm) | production size (max.) WxLxH (mm) | versatility/application potential (-) | formability (-) | aesthetic flexibility (-) | fastening/ installation (screws/adhesives/ interlocking systems, etc.) | possible processing (-) | (dis)assembly strategy (-) |
|---|---|---|---|---|---|---|---|---|
| **PolyAl** | flexible<br>depending on production technique | flexible<br>depending on production technique | high | molded in any producable shape<br>3d print makes complex possible | texture: smooth - rough (matt) depending on production technology (3d printing, compression and injection molding make this possible)<br>color: flexible in color<br>finishing: in mold labeling possible, very flexible in aesthetic, finishing like painting possible with coating<br>much possibilities to influence aesthetic (verchromen) chrome plating | depending on production technique,<br>comparable with wood (also interlock design) and also welding is a possibility | cutting<br>drilling<br>painting (with coating)<br>welding<br>grinding | very flexible possibilities<br>screwing, clicking, pin-hole connection (in injection molding and compression) |
| **Mixed Plastics (DKR350)** | flexible<br>depending on production technique | flexible<br>depending on production technique | high | molded in many producable shape<br>less complex possible,<br>more focus on large object | texture: smooth - rough<br>finishing: texture is possible in compression molding and injection molding (less detailed))<br>color: less flexible in colour (dark colours) | depending on production technique,<br>comparable with wood (also interlock design) and also welding is a possibility | cutting<br>drilling<br>painting (with coating)<br>welding<br>grinding | very flexible possibilities<br>screwing, clicking, pin-hole connection (in injection molding and compression) |
| **compared to** | | | | | | | | |
| **Concrete (portland cement)** | cast in any size | cast in any size | foundations<br>structural beam<br>slabs<br>columns<br>floors<br>walls | molded in any shape | limited<br>finishing possible | bolted<br>welded<br>cast-in-place | cutting<br>drilling<br>grinding<br>polishing | |
| **Steel (S235)** | standard profiles | standard profiles | beams<br>columns<br>trusses<br>framing | flexible in forming techniques | limited in raw state<br>finishing possible | bolted<br>welded<br>riveted connections | cutting<br>welding<br>painting<br>other surface treaments | |
| **Wood (C24)** | depending sheet / planks | depending sheet / planks | walls<br>floors<br>roofs<br>framing<br>furniture<br>cabinetry | flexible in forming techniques | limited in raw state<br>finishing wide range possibilties | nails<br>screws<br>adhesives<br>interlocking systems | cutting<br>drilling<br>painting | |

# appendix 5C: parameter data sustainability

| material | recyclability (%) | carbon footprint (kg $CO_2$e per kg) | sustainable durability (yrs) | mass balance efficiency (low - high) | location of production (onsite / offsite) | material replacement (wood / concrete / steel / etc.) |
|---|---|---|---|---|---|---|
| **PolyAl** | 100% | saves about 1–1.5 kg $CO_2$e per kg of plastic compared to virgin production | depending on application durability ~50+ yrs | high, 100% recyclable | location of resource production off site (ReconPolymers)<br>location of further production depends on production technique requierd | depending on production technique, biggest possibilities for wood |
| **Mixed Plastics (DKR350)** | 100% | saves about 1–1.5 kg $CO_2$e per kg of plastic compared to virgin production | depending on application durability ~50+ yrs | high, 100% recyclable | location of resource production off site (Western Europe)<br>location of further production depends on production technique requierd | depending on production technique, biggest possibilities for wood |
| **compared to** | | | | | | |
| **Concrete (portland cement)** | low possibilities | ~0.4 kg $CO_2$e per kg<br>high | 50+ yrs<br>high | low | offsite, long distance to site<br>transport needed | |
| **Steel (S235)** | 100%<br>but very energy intensive | ~1.9-2.5 kg $CO_2$e per kg<br>high energy usage! | 50+ yrs<br>high | medium | offsite, long distance to site<br>transport needed | |
| **Wood (C24)** | possible<br>not always in same form | ~-0.8 kg $CO_2$e per kg | 50+ yrs<br>high | low | onsite production possible<br>still regular offsite, long distance and transport needed | |

# appendix 5D: parameter data economical

| material | material costs (low/medium/high) | production costs (low/medium/high) | gate fee* (yes/no) * Gate Fee = charged levied | overall costs (low/medium/high) | $CO_2$-emission (low/medium/high) |
|---|---|---|---|---|---|
| PolyAl | low | medium | no | low / medium | low |
| Mixed Plastics (DKR350) | low | medium | yes | low | low |
| compared to | | | | | |
| Concrete (portland cement) | medium / high | low | no | low | medium |
| Steel (S235) | medium / high | high | no | high | high |
| Wood (C24) | high | low / medium | no | low / medium | low |

# appendix 5E: parameter data
# radar chart comparison

**high recyclability**

**reducing reliance on virgin materials**

**low environmental impact**
compared to steel/concrete

**recycling strategy**
to maintain material properties across cycles
> possibility (in loop systems) to maintain material properties across cycles

**replacement of wood**
reduces deforestation

**(non-) / semi-structural applications**

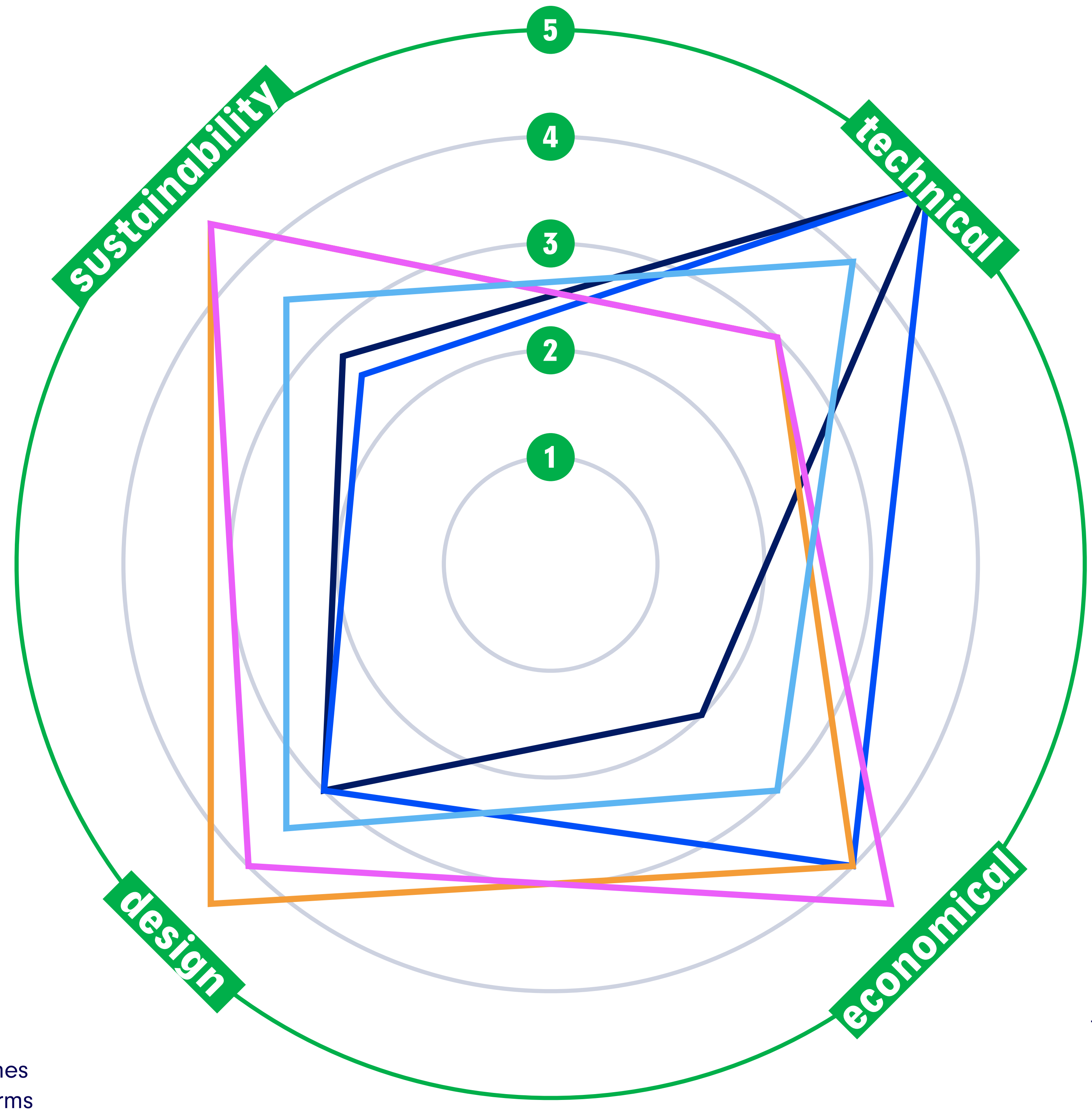
**limited strength**
explore reinforcement methods

**customizable properties**
eg. fire resistance

**durable & weather resistant**

**better thermal performance**
compared to steel/concrete

**comparable to wood**
lightweight, tensile strength, thermal conductivity




**processing versatility**

**high design flexibility**
PolyAl in shapes, colors and finishes
mixed plastics larger & simpler forms

**aesthetic trade-offs**
mixed plastics coarser textures & darker colors

**cost efficienct**

**production efficient**
flexible manufacturing reduce cost

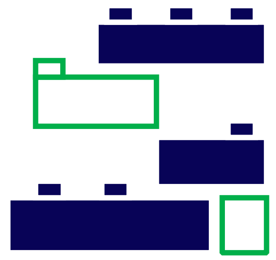
**gate fee for mixed plastics**
global need for innovation

**underutilized resource**
further research and adoption needed

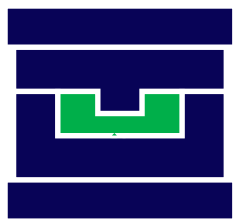
# appendix 6: improve material performance

# appendix 6A: improve material performance
# structural

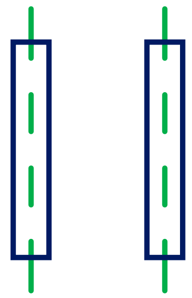
**composite material design**
ex. recycled glass fiber



**interlocking / integrated system design**

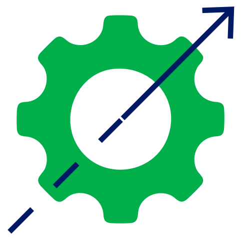


**high-density compression**



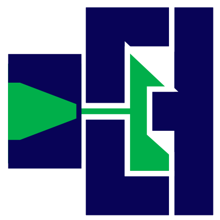
**metal reinforcements**

# appendix 6B: improve material performance aesthetic and acceptance

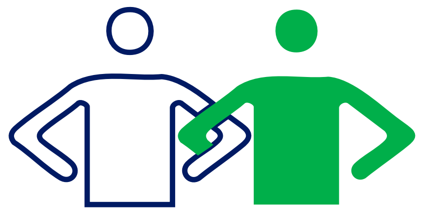


advanced printing / post-processing

shift in perception



use the more refined production (techniques)



collaboration architects, researchers & designers in (aesthetic) innovation