FROM WASTE TO RESOURCES: THE USE OF UPCYCLED PLASTICS IN BUILDING MATERIALS IN THE NETHERLANDS

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ABSTRACT

Plastic waste has posed a major crisis threatening the environment and its inhabitants due to the exponential increase of plastic-derived waste. In the Netherlands, most of the plastic waste was incinerated or shipped overseas, resulting in more greenhouse gas emissions. In response to this accumulation of plastic crisis, upcycling plastic waste as value-added products such as building materials appears to be a more promising solution. Thus, this thesis explores various approaches of using upcycled plastic in the construction industry within the framework of Stewart Brand's shearing layers model, especially the layers of Space plan, System, Skin and Structure. After analyzing the recent literature, it was identified that plastic waste can be served as a reliable material in all four layers, which can reduce 75% of greenhouse gas emissions. In addition, the use of upcycled plastic waste on the skin layer as a facade element seems to be the most favourable option as it is a well-developed material with good heat and sound insulation properties.

KEYWORDS: *Plastic waste, Upcycle, Material flow, Waste management, Shearing layers, Circular economy, Circular building*

I. INTRODUCTION

In recent decades, plastic waste pollution has posed a major threat affecting the ecological environment. Plastic is an important and ubiquitous material heavily relied on by modern society, due to its affordability, lightweight and durable features. According to the report by the European Commission (2018), the use of plastics increased twenty-fold over the past fifty years, rising from 15 million tonnes in 1964 to 311 million tonnes in 2014. However, this increase in usage has resulted in substantially higher risks of plastic leakage to the environment; it is expected that the oceans will contain more plastics than (by weight) before 2050 (World Economic Forum, 2016). Moreover, in the Netherlands, over 580.000 tons (70%) of plastic waste was incinerated for energy recovery in 2017, releasing 770.000 tons of CO_2, which was responsible for approximately 5% of the total climate impact of the Netherlands (CE Delft, 2019). Evidently, burning plastic not only produces more greenhouse gas, but also prematurely terminates the life of plastic. According to research conducted by Schwarz et al. (2021) (see **Appendix A** and **Appendix B**), the average CO_2 emission of energy recovery is 4 kg per kg polymer, which is 4 times of mechanical recycling in the closed loop. Thus, as illustrated in **Figure 1**, this linear approach (R9) is considered to be a less favourable option according to the waste hierarchy (Planbureau voor de Leefomgeving, 2018). In other words, compared with incineration, recycling is a better method to close the plastic loop and boost the circular economy, which can also reduce greenhouse gas emissions by 75%.

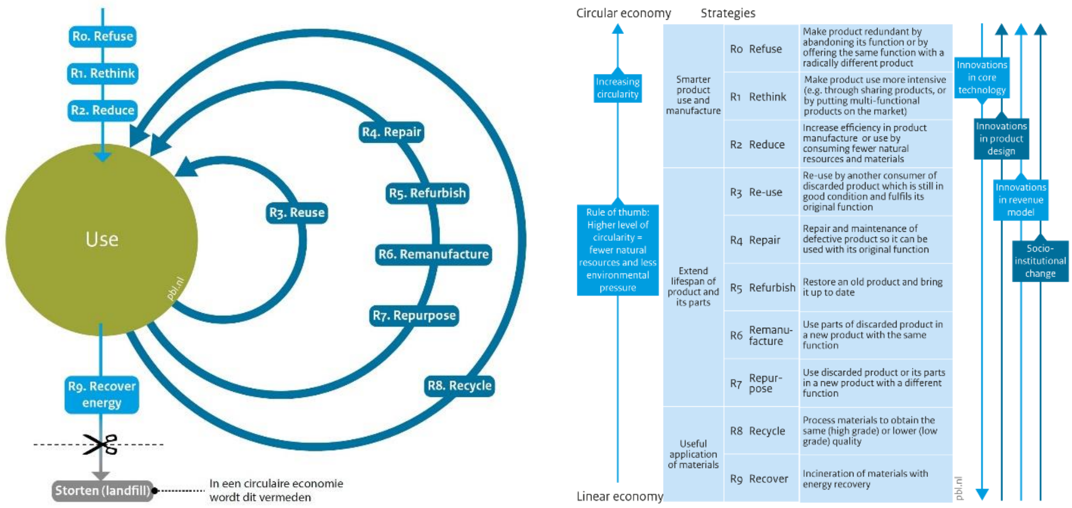


Figure 1. R-ladder (waste hierarchy) within the production chain
Note: From *Circular Economics: What We Want to Know and Can Measure* by Environmental Assessment Agency in the Netherlands

In response to this accumulation of plastic crisis, the Dutch government has set an ambitious target for plastic, aiming to fully transition to a circular economy by 2050 (Dutch government, 2016). In a circular economy, materials are not disposed of or incinerated, but the value is retained in a closed loop within the economic system (World Economic Forum, 2016). Hence, it is vital to find some effective and innovative applications to create value for plastic waste. Due to the characteristics of thermal insulation of plastics, the use of recycled plastic waste as building materials has great potential in reducing the energy demand of buildings, which can save energy by 40% per year (JD Composites, 2019). Yet, the use and development of plastic waste in construction are still very limited. Thus, this thesis specifically focuses on the current application of plastic waste for various construction applications in a framework called "Shearing Layers of Change" proposed by Stewart Brand in 1995. The potential areas of the layers are space plan, system, skin and structure, alongside the current limitations facing its use. The thematic research question in this paper is: **How can upcycled plastic household waste be applied within the shearing layers of Stewart Brand's model?** To answer the research question, the following sub-questions are raised including 1) What are the existing plastic waste flows in the Netherlands? 2) What are the possible benefits and drawbacks of upcycling plastic waste into building materials? and 3) Is it possible to use upcycled plastic waste in the layers of space plan/ system/ skin/ structure?

II. METHOD

To answer the research question mentioned above, several approaches were used in this research.

Material Flow Analysis (MFA) of the household plastic waste in the Netherlands was used in the paper. MFA is a method to comprehensively assess the flows of plastic packaging waste through the respective waste management systems (Brunner & Rechberger, 2016). The data was conducted mainly from two papers by Brouwer et al. (2019) and Picuno et al. (2021) which studied the recycling network of plastic waste for the Netherlands in 2017. By means of the MFA, the current efficiency usage of plastic waste was evaluated, which identified the opportunity of the transition from a linear to a circular plastics economy.

Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was followed to provide an overview of recycling plastic waste as construction materials. SWOT analysis is an essential method to implement while initiating new concepts to the industry (Gurl, 2017). In this study, the implementation of plastic waste in the building industry was evaluated by the literature review and interviews, which included companies and organisations working on innovative use of plastic waste, such as TNO, Conscious Designs and TRANSFORM-CE. Those interviews helped better to understand the state-of-the-art technologies from the industry and shape a common framework of SWOT analysis.

Considering the feasibility of using plastic waste in the reality, the studies on the existing projects were be analysed throughout the study. The case studies concerned the existing solutions of recycling plastic waste in building materials. Within these case studies, the possibilities of the use of upcycled plastic in different shearing layers were described. The overview of the case studies can be found in **Appendix C**.

III. CURRENT PLASTIC HOUSEHOLD WASTE FLOW IN THE NETHERLANDS

There are three main systems for the packaging waste in the Netherlands: 1) a deposit-refund system (DRS) for PET bottles; 2) separate collection for plastic packaging and 3) mechanical sorting for residual waste. The explanation of the three different types of destinations was discussed as follows.

First, the PET bottles are collected by the deposit-refund system (DRS) and recycled as food-grade re-granulate. DRS is a system for PET bottles for carbonated beverages which is an efficient policy instrument to encourage reuse and recycling (Walls, 2011). Purchasers will be charged an additional cost that can later be returned to the collection points such as supermarkets and petrol stations. From 1 July 2021, small plastic bottles are also included in the scheme aiming to increase the recycling rate of plastic bottles (Statiegeld Nederland, 2021). After the collection, the bottles are ground up into small pieces and later turned into new bottles which close the material loop.

Second, the lightweight packaging (LWP) waste is collected separately and then sorted into different categories for recycling. The mixes of post-consumer packaging materials are often referred to as lightweight packages (LWP). Plastic packages are collected via three separate collection schemes for LWP: 1) plastics (P); 2) plastic together with beverage cartons (PD); and 3) plastics together with beverage cartons and metal packages (PMD or PBD). Municipalities that are managing the recycling chain can choose their own collection systems. The most common approach is curbside collection of LWP in wheelie bins for residents in low-rise buildings and drop-off collection for households in high-rise buildings. Subsequently, LWP waste is sorted into different categories including PET bottles, PET trays, PE, PP, film and mixed plastics and has been used to produce high-quality recycled plastics.

Finally, the mixed municipal solid waste (MSW) is collected and sent to further mechanical reprocessing or incineration facilities. This method is used since 2017 due to the low participation rates of recycling in the densely populated urban areas. The separate collection of LWP with wheelie bins in the rural area was successful with participation rates of nearly 100% (Thoden van Velzen et al., 2019). Conversely, in the urban centres in the western part of the country, only small amounts of plastic waste were collected with high levels of non-targeted contributions by using a drop-off collection system to collect LWP waste (Thoden van Velzen et al., 2021). Hence, three mechanical recovery facilities were built in the Western Netherlands namely Alkmaar, Amsterdam and Rotterdam while municipalities decided to stop the separate collection in selected neighbourhoods. In this case, after collecting the plastic waste from the drop-off containers, the waste is distributed to incineration and mechanical pre-treatment. This approach can further sort some valuable plastics from the mixed household waste, and thus increase the amount of waste sent to recycling in addition to the separately collected fractions.

Figure 2 illustrates the plastic packaging waste (PPW) flows from households in the Netherlands in 2017. The production of PPW per capita from Dutch households was 21.77 kg in 2017. As described in the previous section, three different types of destinations are shown in the graph. First, the DRS was performed considerably well in the Netherlands, collecting 95% of

PET bottles, which equalled to 54% of all PET bottles. Second, in contrast, the separate collection rate was relatively low, gathering 38% of PPW only. However, one notable result is that the sorting efficiency is significantly substantial in the separate collection. Third, the residual 58% of PPW was delivered to a distribution process. Approximately 2.5 kg of PPW per capita was separated in this process to mechanical pre-treatment. Subsequently, around 1 kg of PPW was sorted for recycling. Overall, 30% of the waste, which is about 6.5 kg, was recycled for further use while the remaining majority was incinerated for energy recovery.

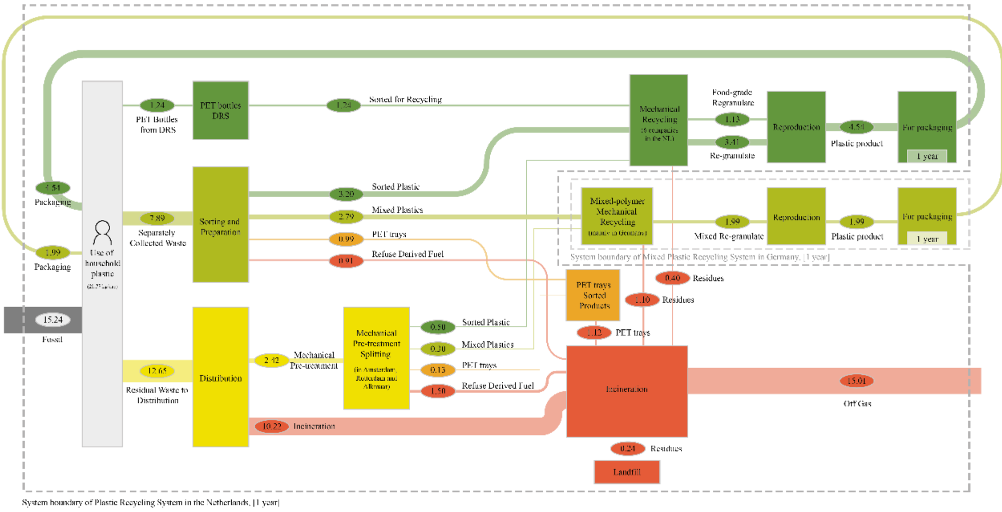


Figure 2. Waste packaging plastic flows from households in the Netherlands in 2017 (kg/cap)
Note: Own creation with data from Picuno et al. (2021)

IV. DISCUSSION OF THE CURRENT FLOW OF PLASTIC WASTE

From the MFA above, it is shown that the Dutch government has developed recycling economies for its plastic waste; however, there is still much room for the improvement of recycling efficiency. In 2017, MSW was mainly transported to municipal waste-to-energy facilities for energy recovery, while 17% was further sent to the mechanical treatment for recycling (Picuno et al., 2021). Thoden van Velzen et al. (2021) noted that although the mechanical treatment for MSW appeals to be a promising method to increase the recycled rates in urban centres, the waste collected from the mechanical treatment is more contaminated than the separate collection, resulting in larger incinerated amounts of sorting residues. For this reason, it is necessary to increase the recycling rates for separate collection as opposed to relying on mechanical treatment.

It is worth noting that the MFA also reveals the necessity to close the loop of mixed plastics. Mixed plastics are often labelled as problematic and not recycled due to their complexity. As shown in the graph, 255.000 tons (15 kg per resident in the graph) of mixed plastic were incinerated while only a few were sorted and sent to the other countries for recycling, releasing 4.000.000 tons of greenhouse gases (Schwarz et al., 2021). Meanwhile, the studies by Bishop et al. (2020) and Jeroen (2020) highlighted that some of the mixed plastic waste in the Netherlands was exported to the developing countries, such as Vietnam and India, without proper waste disposal, which caused a significant amount of plastic waste becoming plastic debris in the ocean. Because of these undesired results, mixed plastics deserve more attention and research to create value instead of being incinerated. This factory launched by Save Plastic in Almere in 2021 not only proved that mixed plastics can be used to manufacture high-value products to close the loop, but also brought the mixed plastic recycling process back to the Netherlands to save the GHG emissions from transportation. More examples of products made by mixed plastics are discussed in Chapter 6.

V. SWOT ANALYSIS OF USING UPCYCLED PLASTIC AS BUILDING MATERIALS

Table 1. SWOT analysis of using upcycled plastic as building materials

Strengths	**Weaknesses**
• Lightweight, compared to conventional building materials • Durable, can be used for 50 years and recycled up to 9 times (Save Plastic, 2021) • Moisture resistance • Effective insulation, which is 16% more energy-efficient than alternative insulation materials (Plastics Europe, 2012) • Easy to maintain and clean	• Too flexible, which stretch and fail under compression instead of breaking • Lack of public awareness and understanding
Opportunities	**Threats**
• Reduce the cost of construction materials, which is about 30% cheaper than conventional materials (Unibrick, 2020) • Save the transportation cost, as the materials are lighter and thinner • Lower the energy usage, saving 75% of energy compared to incineration Schwarz et al. (2021) • Create additional value, making the material circular	• Uncertain due to the lack of research • Doubtful about the safety in the long-term

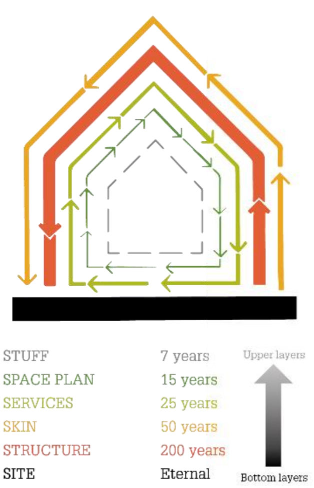
As discussed in the previous chapter, it is important to find some effective and innovative applications to replace incineration while creating value for plastic waste. Thus, it is viable to use upcycled plastic waste in the building industry since various benefits can be seen in this application after analysing **Table 1**. Not only do upcycled plastics reduce costs significantly, but they also make a huge contribution to improving the energy efficiency of buildings which is necessary in order to tackle climate change and preserve resources. However, since the use of upcycled plastic as building materials is a new method that has recently been used in the last decade, the threat of long-term use remains uncertain.

In the following chapter, more in-depth research on the application of upcycled plastic was studied within the framework of “Sharing layers of change”, showing more opportunities and weaknesses of this implementation in different building layers.

VI. Use of upcycled plastics in the shearing layers of change

The idea of presenting buildings in layers based on life expectancy was first introduced by Frank Duffy in 1992, who separated four building timescale layers: Shell, Services, Scenery, and Set. Stewart Brand (1994) expanded Duffy's concept into the six shearing layers. **Figure 3** illustrates the sequence from the bottom layer to the upper layer: Site, Structure, Skin, Services, Space Plan, and Stuff which is also known as Shearing Layers of Change. This model considers the order of the design and construction phases where the bottom layers stay longer than the upper layers. Thus, the bottom building layers and upper service layers have different environmental influences and should be designed separately. As mentioned in Chapter 5, according to Save Plastic (2021), upcycled plastics can be used for 50 years and recycled up to 9 times. By introducing a timeframe in the assessment, the opportunities of using upcycled plastics in different construction layers can be visualized clearly.

This paper excluded the Site layer and Stuff layer since the focus is to explore the possibilities of the use of plastic waste in construction materials. Moreover, the order of the layers was discussed from the upper layers to bottom layers, starting from the basics to the more complicated layers, namely Space Plan, Services, Skin, and Structure. **Figure 4** shows the overview of the use of upcycled plastics in the Shearing layers of change.



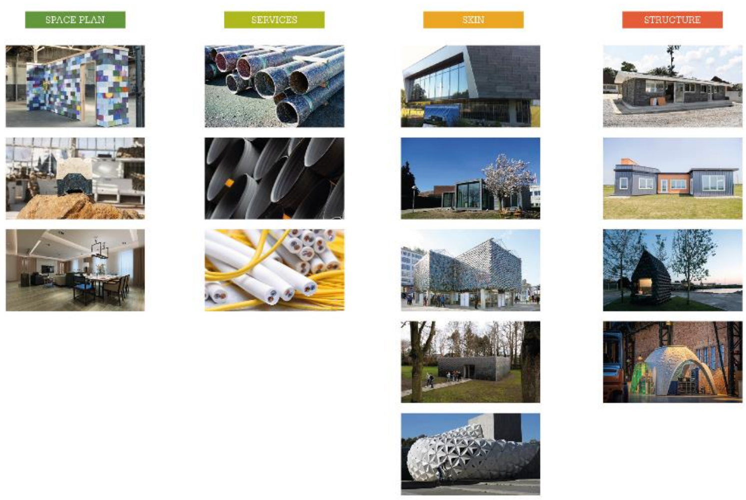


Figure 3 (left). Shearing layers of change by Stewart Brand (1994)
Figure 4 (right). Overview of the use of upcycled plastics in the Shearing layers of change

4.1. Space plan

The Space Plan layer is considered as a layer with a timescale of 15 years, which includes interior walls, ceilings, floors, and doors. In this study, Wall partition and floor covering are discussed. This application is relatively easier than other layers since the required fire resistance standards are relatively lower (Praktijkboek Bouwbesluit, 2012).

4.1.1 Brick for interior wall

First, plastic waste can be used as a replacement for conventional block, brick or wood walls. These plastic walls are made by placing upcycled plastics in heat moulds and pressing the moulds together to form blocks. The first example of this application is the LEGO Bricks designed by Precious Plastic in 2020 (see **Appendix D**). Each brick comprises 1.5 kg upcycled High-Density Polyethylene (HDPE) or Polypropylene, which can be produced within 4 minutes(Precious Plastic, 2020). The hollow design can not only save materials to reduce the cost, but also provide better heat insulation. In addition, the bricks are easy to produce without any special skills and quick to assemble with a hammer, which is ideal for the walls that need to be changed and disassembled frequently.

Appendix E illustrates another example of the replacement of bricks for partition walls. UniBrick was originally designed by Rushabh Chheda during his master's studies at Delft University of Technology. In 2020, cooperated with industrial designer Frans Taminiau, Conscious Designs was founded, with the intention to design plastic bricks for slums and disaster areas. UniBrick is made of 3 kg of upcycled polypropylene (PP) or polyethylene (PE), which can be strengthened by mixing with filler materials like sand from recycled glass (Conscious Designs, 2020). After the reinforcement, these bricks are stronger than cement with high heat insulation and dirt-repellent. Besides, it is 30% cheaper than conventional materials and provides significant CO_2 savings (R. Chheda, personal communication, 17 October, 2021). Similar to LEGO Bricks, the unique shape of UniBrick allows it to be interlocked without using any adhesive like mortar or glue between the bricks, making it easier to disassemble and recycle after use.

4.1.2 Floor covering

Second, the Place N' Go interlocking floor tiles from SelecTech illustrates the use of upcycled plastic for floor covering (see **Appendix F**). Place N' Go flooring is made of 70% of upcycled plastic, with a variety of decorative styles and colours, which can be complemented in any room such as living room and kitchen with a 25-year lifespan (SelectTech, 2019). In addition, as shown in Appendix F, this tile has met different building standards, including fire resistance (ASTM E-648) and static load resistance (ASTM F-970), proving its safety for use in real life. Besides, with the interlocking feature, no adhesive is required, making the tiles easy to install and can be completely recycled into new Place N' Go products.

4.2. Services

The Service layer is considered as a layer with a timescale of 25 years, which includes communication wiring, electrical wiring, plumbing, fire sprinkler systems, HVAC, elevators, and escalators. This study focuses on the possibilities of using upcycled plastic in plumbing, sewage and electricity systems.

4.2.1 Plumbing system

Research showed that it is feasible to use upcycled Polyvinylchloride (PVC) to manufacture water pipes for the plumbing system. Rigid plasticized PVC is commonly used in pipes, window framing, floor coverings, roofing sheets and cables. Wenguang and Mantia (1996) compared the mechanical and processing properties of virgin pipe grade PVC and the upcycled PVC, and found that the upcycled materials not only do not reduce the modulus and tensile strength, but also improve the impact strength and processing behaviour of the pipe grade virgin PVC. This result suggests that PVC cable polymer can be reutilized in close sustainable manufacturing which warrants ecological and economic benefit.

Another application of using upcycled plastics in the plumbing system can be seen in **Appendix G**. Launched in 2019, RPM Pipes are made from 100% upcycled High-density polyethylene (HDPE) with various sizes. HDPE is one of the most commonly used and most in-demand plastics, not only for packaging, but also for construction, especially for pipes, which makes this material the most abundant in the municipal waste stream. By upcycling HDPE waste into water pipes, it can reduce 80% of embodied carbon, from 2.5 kg CO_2 to 0.5 kg CO_2 per kg (RPM Pipes, 2019). Besides, RPM pipes have passed the required tests to gain Department of Transport approval in Australia as an accepted drainage product, such as the thermal stability (ISO 11357-6) and tensile strength (ASTM D-638). Moreover, according to the report by RPM Pipes (2019), this product can remain its stiffness for 50 years, which also fit the timescale of this service layer.

4.2.2 Sewage system

A study demonstrates the viability of using upcycled HDPE in the sewage system. Research by Juan et al. (2020) has shown promising results in the use of upcycled HDPE for the pressure pipe application. By mixing different ratios of upcycled HDPE with raw HDPE with PE100 grade quality, the properties of the blends such as tensile strength, elongation and flexural modulus are all higher than the minimum requirements of PE100 grade, showing their feasibility to be used for the sewage system.

Hence, **Appendix H** illustrates the application of mixing virgin HDPE and upcycled HDPE to make drainage pipes in real life. ECOFLO® 100 is a corrugated dual-wall pipe made from virgin HDPE and a minimum of 40% upcycled HDPE. Moreover, this pipe also complies with several industry standards, such as the specification for polyethylene drainage pipe (ASTM F-2306 and AASHTO M294), which proves its structural properties performance for use in the sewage system. According to Prinsco (2014), the ECOFLO® 100 pipe is two times stronger than traditional virgin AASHTO M294 pipe, and has a lifespan of 100 years, offering a much more durable and greener solution for the sewage system.

4.2.3 Electricity system

The use of upcycled plastics in the electricity system is not common; however, Hedayati et al. (2019) at Swansea University investigated a new method to make carbon electrical cables by using upcycled black plastics (see **Appendix I**). Plastics are made of carbon, hydrogen and sometimes oxygen, which can be broken down and bonded in different arrangements to make materials such as carbon nanotubes. Carbon nanotubes are tiny molecules with beneficial thermal, mechanical and electrical properties (Deng et al., 2016). Hedayati et al. (2019) removed the carbon from recycled black plastics, and found that carbon nanotubes can conduct both heat and electricity. This result reveals that the waste plastics can be converted into electrical cables through a chemical recycling process, which opens up the possibility to close the loop on the circular economy of plastics.

4.3. Skin

This section focuses on the insulation performance of the Skin layer in the “Shearing layer of change”. The Skin layer is considered as a layer for exterior surfaces with a timescale of 50 years, which includes the exterior wall (plus in the insulation layer), exterior wall covering, and roof covering. The operational energy usage is essential in this layer since the building envelope is the most responsible architectural element of the building that impacts thermal comfort and energy balance (CE Delft, 2019).

4.3.1 Exterior wall with insulation

Since the panels investigated by JD Composites also served as load-bearing walls, this example is discussed in the Structure layer below.

4.3.2 Exterior wall covering

The application of upcycled plastic waste in the exterior wall can be seen in **Appendix J**, which shows the example of Oolaboo’s office in Zutphen completed in 2013. The facade of the building is covered by more than 1,000 square meters of panels called Gamplanken, which was made of leftover mixed plastics in the sorting process. Mixed plastic is generally considered low-value and is therefore incinerated; Nevertheless, Gampet Products, the manufacturer of this exterior wall, was renamed Save Plastics, claiming that these plastics can be recycled nine times to create new products (Save Plastic, 2021). Each shelf of Gamplanken measures 1800 x 300 x 35 mm, and weighs approximately 15 kg. Moreover, based on research by TNO (2015), Gamplanken is beneficial for the climate since plastic is a high-quality element for heat and cold insulation.

With the success of Gamplanken, Save Plastic constructed a self-sufficient and movable house called Save Home in Arnhem in 2020, which consists of 10,000 kg mixed household plastic waste (see **Appendix K**). In order to demonstrate the feasibility of living in a plastic house comfortably, Bram Peters, the founder of Save Plastic, decided to build a house with mixed plastics and live there. In the beginning, the project was aimed at building with 100% plastic waste; however, due to the requirements of Dutch building standards, the outer shell of the house was made of plastic waste while the inner structure was made from wood and steel. By using upcycled plastic on the facade and the roof, the house has achieved a high degree of heat insulation with low thermal conductivity, which is twice as effective as ordinary houses (Save Plastic, 2021). In addition, according to the report provided by Save Plastic (2018), the production of the facade tile emits a mere 0.7 kg of CO_2 per kg, which is 80% less than incinerating mixed plastic waste.

Apart from the mixed plastics, it is also practicable to use upcycled household plastic and polyvinyl chloride (PVC) on the facade for exterior wall and roof covering. A Dutch company Grosfeld Bekkers van der Velde Architecten investigated the use of upcycled plastic on facades called Pretty Plastic and applied it in two building projects. In cooperation with two architecture firms Overtreders W and bureau SLA, the People's Pavilion was temporarily exhibited in the Dutch Design Week 2017 in Eindhoven (see **Appendix L**). The coloured plastic shingles on the pavilion's facade were made from plastic waste provided by the Eindhoven residents to demonstrate the potential of forming a circular economy. This success led to a greater challenge: the application of a permanent building called Music Pavilion for the Sint Oelbert School in the Netherlands (see **Appendix M**). Cooperating with a Belgium recycling company Govaplast, Pretty Plastic produced grey diamond-shaped shingles from PVC waste of the building industry such as window frames, downspouts and rain gutters. Besides, the tiles were designed to minimize the use of glue and steel frames. In this case, the tiles can be reused or recycled after the structure is demounted, contributing to a circular economy. In 2019, the tiles obtained a Class B fire protection certification (very difficult to burn), proving their safety as a cladding material for external walls (Pretty Plastic, 2021).

4.3.3 Skin covering

The ArboSkin pavilion by Stuttgart University's ITKE Institute illustrated another application of plastics in the skin layer (see **Appendix N)**. The pavilion was composed of 388 three-dimensional triangulated panels made from a specially-developed bioplastic, marking the first occasion for the development of bioplastic sheets. Produced by a German firm Tecnaro, the bioplastic Arboblend combines over 90% of renewable resources such as biopolymers, with natural reinforcing fibres, which can be composted or disposed of almost carbon-neutrally. This element has shown its fire resistance (DIN 4102-B1) with high durability, which can be applied on both interior and exterior walls (De Corato, 2021). Besides, for the construction of the bioplastic, the component can be "drilled, printed, laminated, laser-cut, CNC-milled, or thermoformed to achieve different surface qualities and structures" (Tecnaro, 2013). In this project, 3.5 mm thick extruded sheets were thermoformed into identical pyramidal moulding components, which formed a double-curved skin structure, revealing the potential of using bioplastic sheets on the facade, especially serving as self-supporting precast panels.

4.4. Structure

The Structure layer is considered as a layer with a timescale of 200 years. The load-bearing building components are usually constructed with steel, timber and reinforced concrete. Compared with the Skin layer, the material in the Structure layer focuses on the strength of the structure and fire resistance instead of the insulating ability. The Structure layer includes the foundation, column, structural wall, and beam; however, since not enough research has been conducted into the investigation of using upcycled plastics as structural materials, this paper concentrates on the structural walls.

4.4.1 Structural brick wall

Current research revealed that plastic bricks can only partly be used as a structural material. Sierra Jiménez (2016), who studied the feasibility of using upcycled High-density Polyethylene (HDPE) in housing for structural elements by analysing a housing project in Colombia designed by Conceptos Plasticos (see Appendix O), concluded that even though the plastic material is cheaper than conventional structural materials, such as wood and masonry, there are limitations on using upcycled plastic in construction. Hence, it is more feasible to use the structure component made by upcycled plastic in temporary buildings, for example, in emergency shelters.

The main reason for this constraint is the flexibility of plastic. Although plastics have a similar property in strength with clay bricks and masonry, the predominant distinction is the buckling failure. As plastic is elastic, it will slowly stretch and fail under compression instead of breaking, constituting structural instability without awareness in the long term. Meanwhile, the lateral load test proved that the plastic wall may lose its rigidity and resistance over time because it can support lateral displacements up to 250mm and continue to deform proportionally. In this sense, plastic structural wall is very likely to suffer severe damage without people noticing, which is not ideal for structural components.

Furthermore, another issue of using plastic bricks as a structural material is the gap between bricks due to their large thermal expansion coefficient. The expansion coefficient for plastic bricks are 20 times higher than clay bricks, causing a significant volume change (Wadsö & Svenmyr, 2019). Since we might use plaster and paint to tighten the construction from drafts through walls, the change of volume and movement when exposed to diagonal pressure may result in cracks on the structural wall. Hence, it is undesirable to use plastic bricks as a load-bearing material in areas of fluctuating climate and temperatures.

4.4.2 Structural insulated panel

Although it is not feasible to use upcycled plastic bricks as a structural component, it is possible to use it as an element in the structural insulated panels (SIP). In 2019, JD Composites erected a beach house in Canada made of approximately 612,000 upcycled plastic bottles (see Appendix P). They developed structural insulated panels made of 100% upcycled PET bottles that are bonded with specialized laminates. Structural insulated panels are high-performance building systems used for residential and light commercial construction which have significant advantages in strength, thermal performance and speed of installation compared with the traditional timber frame construction method (Kermani, 2006). According to the report by JD Composites (2019), the panels made of upcycled PET bottles are impermeable to water and moisture absorption and well-insulated, which is at a continuous R-30 level with no thermal bridging, saving 33 GJ per year. In addition, for the structural capability, the panels have been proven to withstand a 524 km/h sustained wind force. Hence, by sandwiching the upcycled PET foam core between fibreglass skins, the panels performed well as a load-bearing structure.

4.4.3 3D printed structure

Recent research has shown that it is possible to use plastic as a structural element through 3D printing. Currently, most of the 3D printed construction projects are using concrete, which is not environmentally friendly since it has a higher carbon footprint. As shown in Appendix Q, DUS Architects launched a project called 3D Print Canal House in 2014, which aimed to print a 700m^2 house completely made with bio-based plastic for offices and workspaces. It was supposed to be printed room-by-room, with dimensions of 2x2x3.5 metres, by a gigantic 3D printer called Kamermaker, and assembled into one house (DUS Architects, 2014). The project was expected to be finished in 2018; however, in the interview, DUS Architects mentioned that they were facing difficulties in printing the structural trusses because of the limited build volume of the 3D printer (H. Vermeulen, personal communication, 13 December, 2021). As a result, an 8m^2 urban cabin prototype in Amsterdam was built with a structural facade ornament using a black bio-based plastic, which can be fully recycled and reprinted in the following years. This is a practical example showing the possibility of the use of 3D printed plastic in building as a structural element, despite the fact that more in-depth research is needed such as the feasibility of scaling up and the connections between the printed elements.

Another example of the application of 3D printed plastic for structure is the R-IGLO pavilion designed by Royal 3D in 2020 (see **Appendix R**). The material of this pavilion is PET plastic from the Rotterdam Port, reinforced with 30% glass fibre, which can be recycled, forming a circular economy. With the Continuous Fiber Additive Manufacturing (CFAM) printer, a self-supporting structure can be printed in an industrial scale volume (4x2x1.5 metres), while adding glass fibre to increase the strength and stiffness (Port of Rotterdam, 2020). Moreover, the igloo-like shell comprises several 3D-printed modules which can be disassembled, stored and transported for further use, allowing customisation and prefabrication.

VII. CONCLUSIONS

As plastic waste is inevitable at the end of usage, it is vital to manage this waste while improving environmental sustainability. It is viable to use upcycled plastic waste as construction materials since upcycled plastics are energy and resource-efficient, which provide quality performance over a long lifespan compared to conventional materials. This paper studied the current usage of upcycled plastic waste for construction applications in different shearing layers. Based on the overview, the following conclusions can be drawn:

- The use of plastic waste for construction applications has the ability to solve both the greenhouse effect and plastic soup issues. In addition, the use of plastic waste in different construction applications supports the transition towards a circular economy.

- It is necessary to increase the recycling rates for separate collection as opposed to relying on mechanical treatment.

- The study has proven that upcycled plastic waste can be applied in the upper layers, namely Space Plan, Service, and Skin, since the building standards of the upper layers are much lower. In contrast, more research on the structural performance of upcycled plastics is needed in the Structure layer.

Despite the numerous limitations of the application of upcycled plastic in the construction field, its prospect is still broad with the development of research and technological progress. With more studies in the coming years, the use of upcycled plastic waste for construction purposes may become more common in the future.

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Back

Appendix A

CO_2 EMISSIONS OF POLYMERS PER KG POLYMER

Climate change (kg CO_2 eq. / kg polymer)		Polyolefins				Monomer forming polymers				Depolymerization/ hydrolysis polymers		
		PP	LDPE	LLDPE	HDPE	PS	EPS	HIPS	PMMA	PA (nylon 6)	PET	PLA
High relative CO_2-eq.	Incineration	5.2	5.3	5.1	5.2	7.0	6.8	7.0	9.4	10.1	5.4	3.2
	Energy recovery	4.3	4.1	3.9	3.9	5.9	5.9	5.9	8.7	9.4	4.7	2.7
	Pyrolysis (Energy)	1.9	1.9	1.7	1.8	3.4	3.3	3.4	7.2	7.5	3.4	3.2
	Gasification (Energy)	1.5	1.7	1.4	1.5	3.6	3.5	3.6	7.0	7.2	3.3	2.3
	Pyrolysis (Wax)	1.6	1.7	1.4	1.5	3.1	3.0	3.1	6.9	7.2	3.0	2.9
	Mechanical (Open loop)	2.0	2.0	1.9	1.9	3.0	2.9	3.0	5.0	5.2	2.5	2.2
	Pyrolysis (Monomers)	1.3	1.4	1.2	1.3	1.5	1.4	1.7	2.7	2.9	2.9	2.5
	Gasification (Monomers)	1.0	1.1	0.8	0.9	2.4	2.3	2.5	6.6	6.9	2.6	2.5
Low relative CO_2-eq	Mechanical (Closed loop)	1.4	1.3	1.3	1.3	1.8	1.8	1.8	2.4	2.6	1.5	1.0
	Dissolution	1.6	1.6	1.6	1.6	1.8	1.8	1.9	2.0	2.2	2.3	-
	Depolymerization	-	-	-	-	-	-	-	-	1.6	1.3	-
	Hydrolysis	-	-	-	-	-	-	-	-	-	-	1.3

Climate change (kg CO_2 eq. / kg polymer)		Complex polymers												Thermoset polymers	
		ABS	PVC	EVA	EVOH	PA (nylon 66)	PAN	PBT	PC	PEEK	POM	PSU	PTFE	PUR	Epoxy resins
High relative CO_2-eq.	Incineration	7.8	4.0	4.4	7.7	10.6	8.9	5.5	10.3	14.5	3.4	10.7	138.9	6.7	7.6
	Energy recovery	6.8	3.4	3.6	6.9	9.9	8.1	5.0	9.5	13.7	3.0	9.9	138.7	5.8	6.6
	Pyrolysis (Energy)	4.4	2.0	2.3	5.5	8.1	5.6	3.4	8.0	11.6	2.5	7.9	137.4	4.7	5.2
	Gasification (Energy)	4.5	2.0	1.7	5.1	7.7	5.9	3.1	7.8	11.7	1.8	8.2	137.6	4.4	5.1
	Pyrolysis (Wax)	4.1	2.1	2.0	5.1	7.8	5.3	3.0	7.7	11.3	2.2	7.7	137.1	4.3	5.0
	Mechanical (Open loop)	3.5	1.9	1.9	3.9	5.6	4.3	2.6	5.4	7.7	1.7	5.6	83.0	-	-
	Pyrolysis (Monomers)	4.2	2.2	2.0	5.3	7.6	5.1	2.8	7.4	10.9	2.0	7.4	70.6	4.3	4.7
	Gasification (Monomers)	3.9	2.0	1.5	4.7	7.4	5.0	2.7	7.2	10.7	2.0	7.2	137.0	4.0	4.5
Low relative CO_2-eq	Mechanical (Closed loop)	2.0	1.2	1.2	2.1	2.8	2.3	1.6	2.6	3.6	1.1	2.8	33.7	-	-
	Dissolution	1.8	1.5	1.5	1.9	2.2	2.0	1.7	2.3	2.5	1.4	2.3	15.0	1.8	2.0
	Depolymerization	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hydrolysis	-	-	-	-	-	-	-	-	-	-	-	-	-	-

CO_2 emission reduction: 0% – 100%

About 4 kg CO_2 emission per kg of polymer for energy recovery

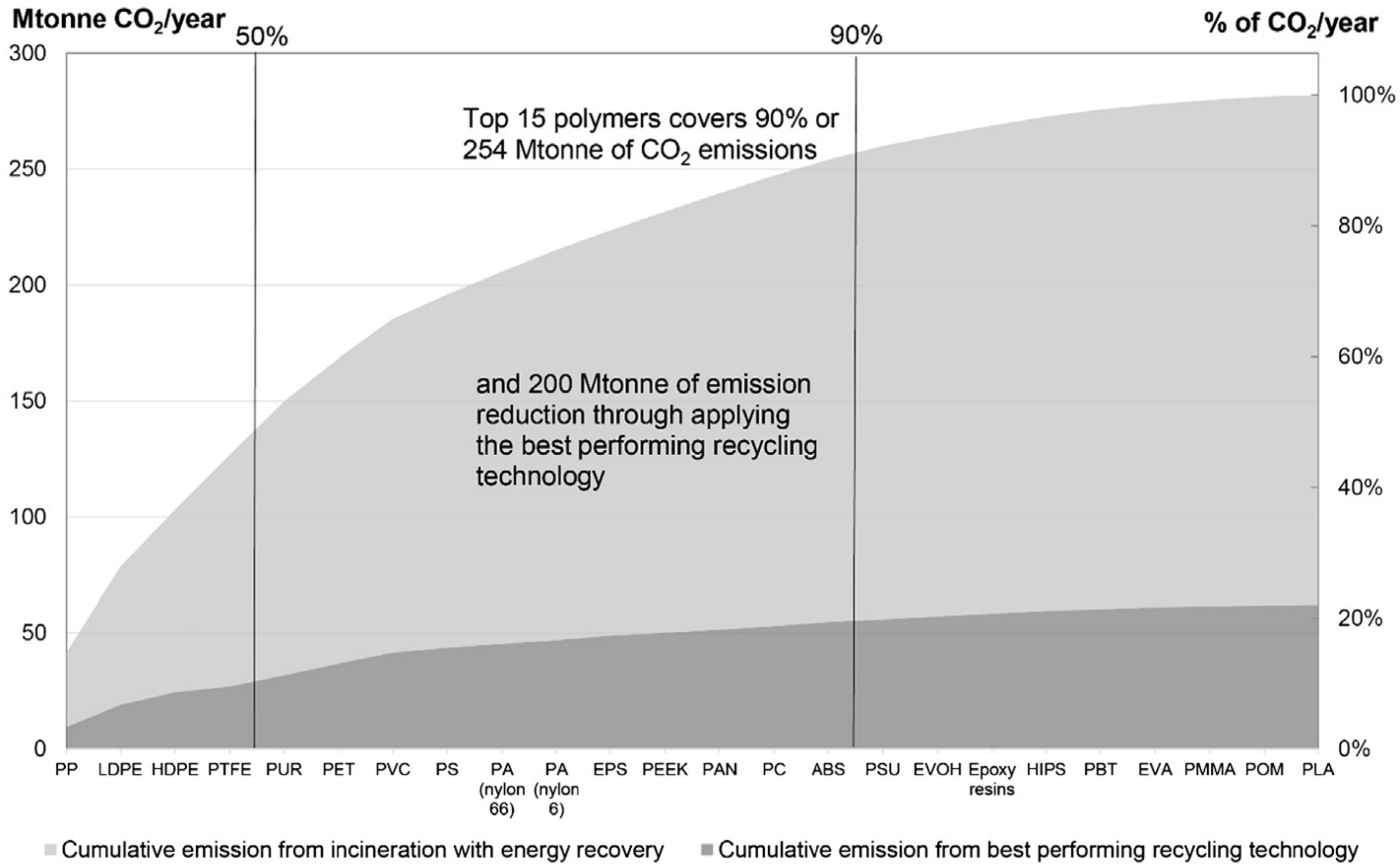
Source:

Schwarz, A. E., Ligthart, T. N., Bizarro, D. G., De Wild, P., Vreugdenhil, B., & van Harmelen, T. (2021). Plastic recycling in a circular economy; determining environmental performance through an LCA matrix model approach. Waste Management, 121, 331-342.

Back

Appendix B

CO EMISSIONS COMPARSION OF ENERGY RECOVERY AND RECYCLING



Source:
Schwarz, A. E., Ligthart, T. N., Bizarro, D. G., De Wild, P., Vreugdenhil, B., & van Harmelen, T. (2021). Plastic recycling in a circular economy; determining environmental performance through an LCA matrix model approach. Waste Management, 121, 331-342.

Back

Appendix C

OVERVIEW

Use of upcycled plastics in the "Shearing layers of change"

SPACE PLAN



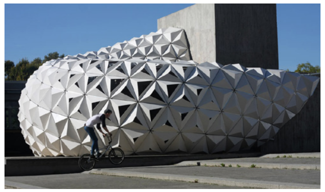
SERVICES



SKIN







STRUCTURE




Back

Appendix D

LEGO BRICKS

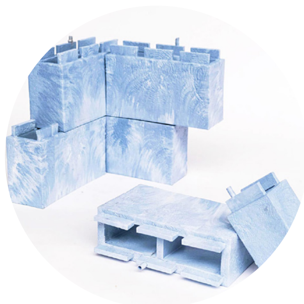
by Precious Plastic

SPACE PLAN

Insulation

Information

Location:	Netherlands
Year:	2019
Program:	Wall
Building material:	recycled PP or HDPE
Size:	160 x 180 x 70 mm
Weight:	1.5 kg (per brick)



The brick design is published open-source, meaning that anyone can download the drawings online, for free, and start turning plastic waste into a useful building material.

The bricks are easy to produce without any special skills and quick to assemble with a hammer – perfect for temporary structures after natural disasters or long term structures like low cost housing and public buildings.

Precious Plastic's brick, which uses 1.5 kilos (3.3 lbs) of plastic waste and takes about 4 mins to produce, addresses both these challenges.

Precious Plastic instead created a "how-to" tutorial for making the brick that uses our open source machinery already operated by more than 400 independent Precious Plastic projects around the world.

Source:
https://preciousplastic.com/starterkits/buy/bricks.html
https://designwanted.com/architecture/precious-plastic-brick/

Appendix E

UNIBRICK

by Conscious Designs

SPACE PLAN

Fire resistance Insulation

Information

Location:	Netherlands
Year:	2020
Program:	Wall
Building material:	recycled PP or HDPE
Size:	200 x 100 x 135 mm
Weight:	1.6 kg (per brick)

These bricks can be used as giant building blocks to make many modular and circular designs.

Each brick is made of 1.6 kilos of 100% recycled plastic. The current samples are made using Polypropylene which we source ourselves from our local community in Rotterdam. All the collected material is brought to our workshop, where we sort and clean the plastics, before shredding it into small pieces of up to 9mm, which is used to make the bricks.

These bricks can be locked together using M8 threaded rods, that go through the holes provided in the bricks and locked using standard nuts, this gives you the flexibility to make various modular and circular designs.

They are available in up to 17 different colors, in PP and 4 colors in HDPE.

Source:
https://www.consciousdesigns.nl/unibrick-samples
https://www.bluecity.nl/blog/we-empower-local-communities-to-benefit-from-local-plastic-waste-interview-with-bluecitizen-frans-taminiau-and-rushabh-chheda-from-the-unibrick/

Back

Appendix F

PLACE N' GO

by SelechTech

SPACE PLAN

Information

Location:	United States
Year:	-
Program:	Floor
Building material:	70% recycled plastic
Size:	470 x 470 mm
Weight:	2.5 kg (per tile)

Place N' Go Flooring is an adhesive-free, interlocking modular floor tile system. Each 18.5"x18.5" tile is comprised of an injection molded, flexible vinyl base, that provides a "built-in underlayment" and a hidden interlock system; and a 2 mm thick finish layer.

Place N' Go's design provides effective performance in manufacturing environments. Its flexible but beefy construction and the weight of the tile allow it to be installed, adhesive free, over existing floors, with little or no floor preparation.

Source:
https://placengo.com/products/
https://placengo.com/wp-content/uploads/2019/11/PlaceNGo.pdf

PLACE N' GO

Product sheet

SPACE PLAN

Fire resistance
Insulation

PLACE N'GO by SelecTech

Flooring by SelechTech, Inc.

Construction	
Dimensions (finished surface)	18.5" x 18.5" 47.0 cm x 47.0 cm
Coverage	2.38 sq ft/tile 0.22 sq meter/tile
Thickness	5/16" 7.94 mm
Commercial Wear Surface	10 mil (0.25mm) PVC Ceramic/Urethane Wear Coat
Weight	5.4 lbs/tile
Packaging	8 tiles/box 19.04 SF/ box

Performance Characteristics	
Noise Reduction	Excellent
Underfoot Comfort	Superior
Stain Resistance	Excellent
Maintenance Requirements	No Wax
Made in USA	
Warranty	25-Year Residential Warranty

Physical Properties	
Abrasion Resistance	<0.01 gram weight loss **ASTM D-3389**
Coefficient of Friction	0.70
Conforms to ADA	**ASTM D-2047**
Critical Radiant Flux	>0.45 watts/cm²
Meets Class I Fire Rating	**ASTM E-648**
Smoke Density	≤450 **ASTM E-662**
Static Load Resistance	250 psi **ASTM F-970**

Environmental Quality	
Air Quality Meets Requirement for LEED IEQ 4.3	CA Prop. 1350 IEQ Protocol
Recycled Plastic Content	70%
Quality System	ISO 9001
LEED	Use of Place N' Go flooring can contribute to points in Materials and Resources, Regional Materials, Indoor Environmental Quality, and Innovation Credit categories.

Back

Appendix G

RPM PIPE

by RPM Pipes

SERVICES

Fire resistance

Insulation

Information

Location:	Australia
Year:	2019
Program:	Water pipes
Building material:	Recycled plastics
Size:	varies, 6m long
Weight:	varies

RPM can fabricate custom designs to join and connect many different things using our pipe. Below are a selection of projects in which RPM have created unique solutions for our customers to provide distinctive outcomes for those "one of a kind" appl ications. Talk to RPM about your piping requirements that you can't find an answer to, we may already have a solution or can work with you to create one.

RPM Pipes have been making bay outlets since the early 90’s before they started manufacturing their own pipe, They offer a range of bay outlets to suit a variety of appl ications, suppl ied separately to fit to existing pipes or pre-fitted to RPM pipes. Repairs and servicing is also avai lable on RPM products.

Source:
https://rpmpipes.com.au/
http://rpmpipes.com.au/resources/rpm-product-catalogue-2019/

Back

Appendix G

RPM PIPE

Product sheet

SERVICES

Fire resistance

Insulation

Key results and benefits of RPM Pipes,

- RPM Pipes are classified as SN6 (6,000 N/mm)
- 100% recycled plastic
- Reduction of Embodied Carbon from 2.5kgCO2eg/kg to 0.5kgCO2eg/kg by using RPM Pipes
- Australian made and owned
- Manufactured in regional Victoria

Pipe Testing Results

Pipe Property	Unit	Value	Standard
Ring Stiffness (Short term)	N/m/m	>6,000	AS/NZS 1462.22
Ring Stiffness (2 year)	N/m/m	>3,000	AS/NZS 2566.1
Ring Stiffness (50 year)	N/m/m	>2,500	AS/NZS 2566.1
Creep ratio (2 years)		3	ISO 9967

Material Property	Unit	Value	Standard
High Density Polyethylene (HDPE)		100% recycled	
Melt Flow Rate (190°C/2.16kg)	g/10min	0.7 -0.8	ASTM D 1238
Melt Flow Rate (190°C/5kg)	g/10min	2.0-3.0	ASTM D 1238
Melting Point	°C	133	ASTM D 3418
Thermal Stability	minutes	42	ISO 11357-6
Density	g/cm^3	0.961	ASTM D 792
Tensile Strength (Yield)	MPa	27	ASTM D 638
Tensile Strain (Yield)	%	9	ASTM D 638
Flexural Modulus	MPa	1098	ISO 178 -A
Impact Strength	kJ/m^2	7.5	ISO 179

Back

Appendix H

ECOFLO®100

by Prinsco

SERVICES

Fire resistance

Insulation

Information

Location:	United States
Year:	-
Program:	Sewage pipes
Building material:	40% recycled HDPE
Size:	-
Weight:	-

ECOFLO®100 is an industry first: a high density polyethylene pipe containing a minimum of 40% recycled HDPE and engineered to provide a 100 year service life.

It offers material performance exceeding the requirements of AASHTO M294 or ASTM F2306, and is the ideal choice for high-volume watertight gravity-flow drainage applications where an environmentally-conscious product is in demand.

ECOFLO100 can be ordered with bell and spigot ends which are manufactured to meet ASTM D3212 watertight laboratory test requirements.

Source:
https://www.prinsco.com/prinsco-markets/products/ecoflo100-residential/
https://www.prinsco.com/wp-content/uploads/2014/06/Prinsco_ResidentialCatalog_Final3.pdf

Back

Appendix H

ECOFLO®100

Product sheet

SERVICES

ECOFLO®100 is an industry first: a high density polyethylene pipe containing a minimum of 40% recycled HDPE and engineered to provide a 100 year service life. It offers material performance exceeding the requirements of AASHTO M294 or ASTM F2306, and is the ideal choice for high-volume watertight gravity-flow drainage applications where an environmentally conscious product is in demand.

Available Sizes

Diameter (in.)	Number	Nominal Length (ft.)
4"	4EF20NP	20'
6"	6EF20NP	20'
8"	8EF20NP	20'
10"	10EF20NP	20'
12"	12EF20NP	10'/20'
15"	15EF20NP	10'/20'
18"	18EF20NP	10'/20'
24"	24EF20NP	10'/20'
30"	30EF20NP	10'/20'
36"	36EF20NP	10'/20'
42"	42EF20NP	10'/20'
48"	48EF20NP	10'/20'
60"	60EF20NP	10'/20'

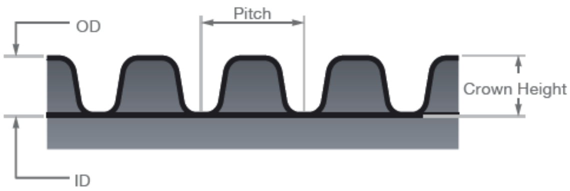
Some sizes may be special order. Available perforated.

Industry Standards

ECOFLO®100 pipe meets the following:

- **ASTM F2306:** Standard Specification for 12" - 60" (300 - 1500 mm) Annular Corrugated Profile-Wall Polyethylene (PE) Pipe and Fittings for Gravity-Flow Storm Sewer and Subsurface Drainage Applications*
- **ASTM F477:** Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
- **ASTM D3212:** Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals

Dual-Wall Pipe Wall Cross



Material Performance

ECOFLO®100 is engineered using a proprietary resin blending technology to ensure premium stress crack resistance (SCR). In fact, independent tests have verified that ECOFLO 100's material performance vastly exceeds the requirements of AASHTO M294. That's remarkable considering that ECOFLO 100 is made from partially recycled content.

Service Life

ECOFLO 100 has been independently tested and verified to meet the rigorous 100 year service life protocol — an unprecedented standard for green-friendly pipe. That is made possible, in part, by our proprietary antioxidant package, which effectively erases the cycle history of our recycled blend and eliminates the chance for chemical degradation.

Structural Performance

ECOFLO100 is a corrugated dual-wall pipe made from high density polyethylene (HDPE), which is proven to provide the same level of long-term structural performance you have come to expect from traditional virgin AASHTO M294 pipe.

*See our ECOFLO100 Product Page and Resource Library at prinsco.com for complete details.

SERVICES

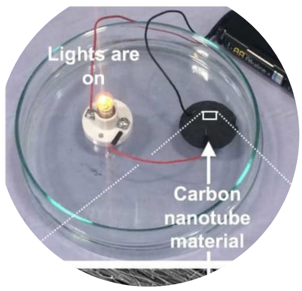
Fire resistance

ELECTRICITY CABLES

by Swansea University

Information

Location: United Kingdom
Year: 2019
Program: Electricity cables
Building material: Black plastics
Size: -
Weight: -



The research, published in the Journal of Carbon Research is said to focus on chemical recycling which uses the constituent elements of the plastic to make new materials.

Plastics are made of carbon, hydrogen and sometimes oxygen, and can be broken down into these elements and bonded in different arrangements to make materials such as carbon nanotubes.

During the study, the research team tested plastics, in particular black plastics, which are commonly used as food packaging but can't be easily recycled. They removed the carbon and then constructed nanotube molecules from the bottom up using the carbon atoms, then used the nanotubes to transmit electricity to a light bulb in a small demonstrator model.

Source:
https://www.theengineer.co.uk/plastics-swansea-electricity-cables/

Appendix J

SKIN

Fire resistance Insulation

OOLABOO'S OFFICE

by Gampet Products (Save Plastic)

Information

Location:	Zutphen, Netherlands
Year:	2013
Program:	Facade
Building material:	recycled mixed plastic
Size:	1800x300x35 mm
Weight:	1 kg (per tile)

Gamplanken is produced by Gampet Products in Ulft, the Netherlands. For the past 25 years, they have been producing products such as Gamplanken from waste plastics that otherwise would have been burned in an incinerator. To date, the material has been mainly used as sheet piling for construction operations and the lining of waterfronts and banks. However,

Gamplanken has recently seen its first architectural application in the new headquarters and warehouse of Dutch cosmetics company Oolaboo. Located in an industrial district within the Dutch municipality of Zutphen, the exterior of the building is clad with Gamplanken panels that measure 1800 x 300 x 35 mm each. In total, 20,000 kilograms of waste plastic were processed and recycled to dress this very large building. plastics.

Source:
https://materialdistrict.com/article/plastic-scraps-become-cladding-innovation/
https://www.bouwwereld.nl/producten/gevelbekleding-met-planken-uit-plastic-afval/

Back

Appendix K

SAVE HOME

by Save Plastics

SKIN

Fire resistance

Insulation

Information

Location:	Arnhem, Netherlands
Year:	2020
Program:	Housing
Building material:	recycled mixed plastic
Size:	75 m^2
Weight:	10.000 kg (total)

Save plastics introduces a home that can be movable and self-sufficient, produced with local waste plastic. The save home is the first house that combines the four elements of 'good green living': comfort & safety, self-sufficiency, mobility and local circular production.

The save home is a portable home that does not compromise on luxury and comfort. The house consists of separate units that can be connected as desired. Thanks to smart placement, good insulation, solar collectors and the latest technologies, the house can be self-sufficient. Where possible, 100% recycled plastic is used. For example, the facade is completely covered with plastic, as well as the outdoor terrace. Other materials used are as sustainable as possible.

Source:
https://www.saveplastics.nl/oplossingen/save-home/
https://savehome.nl/

SAVE HOME

Product sheet

SKIN

Fire resistance Insulation

ENVIRONMENTAL PRODUCT DECLARATION

According ISO 14025 and EN 15804

save plastics

NIBE EXPERTS IN SUSTAINABILITY

NATURE-LINE BLACK

COMPANY INFORMATION / DECLARATION OWNER

Manufacturer: Save Plastics
Production Location: Save Plastics
Address: Westervoortsedijk 73-FC
NL-6827 AV Arnhem
E-mail: info@saveplastics.nl
Website: www.saveplastics.nl

EPD INFORMATION

Calculation number: EPD-NIBE-20181031-3171
Date of issue: 01-11-2018
End of validity: 01-11-2023
Version NIBE's EPD Application: 1.0
Version database: v2.73 (2018-10-30)
PCR: SBK bepalingsmethode v2.0 incl. Wijzigingsblad overgang naar EcoInvent v3.3 of 1th June 2017

VERIFICATION OF THE DECLARATION

CEN standard EN 15804:2012 serves as the core PCR
Independent verification of the declaration. according to EN ISO 14025:2010. ☐ Internal ☒ External

De methodologie en dataverzameling zoals beschreven in dit rapport voldoet aan de eisen van normen ISO 14040/44, ISO 21930 en tevens aan de eisen van de "Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken versie 2.0 van november 2014, inclusief wijziging 1 juni 2017"

Daarmee wordt voldaan aan de eisen uit toetsingsprotocol versie 2.0 van november 2014, inclusief wijziging 1 juni 2017.

Jansen

Third party verifier: Kamiel Jansen [reviewer], NIBE

DECLARED UNIT

1 kg of gerecyclede kunststoffen voor de openbare ruimte
Wordt toegepast in verschillende toepassingen zoals: palen, planken, balken en meubilair voor de openbare ruimte

SCOPE OF DECLARATION

A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	X	X	X	X	MND	MND	MND	MND	X	X	X	X	X

(X = included, MND = module not declared)

PRODUCT DESCRIPTION

Nature-line products for urban constructions. The Nature-line is made from Post-Consumer waste plastics, produced into products for Light poles, sheetpiling, timbering, cladding, marina decks, jetty's and parkbenches. The Nature-Line products are an alternative for wood, steel or concrete products.

DESCRIPTION OF THE MANUFACTURING PROCESS

Preparation Process of Save Plastics

The raw material is delivered to HK in the shape of cuboid pressed bales.

At first, the bales, both film, and mixed plastics run through a shredder, where the material gets reduced to small pieces. The raw material which is used is a waste product which has a negative value.

Due to a band-conveyor, the crushed plastics pass a magnetic separator on their way to the wind sifter. At this point, the first two waste streams arise – metal and heavy plastics.

The remaining good material is carried to a dryer by air. A heating machine that is run by natural gas delivers a warm airflow into the dryer. Having humidity eliminated paper parts are the next to be removed. A so-called Mechanical-dry-Cleaner, equipped with a certain kind of paddles, whips the plastic pieces. Paper fabrics, which sit on the plastics, fray and disengage themselves from the plastics.

The dry and clean plastic shreds now arrive at the pelletizer, where they become plastic pellets. These pellets can be fed into an extruder to produce a variety of end products

Appendix K

SAVE HOME

Product sheet

SKIN

Fire resistance

Insulation

ENVIRONMENTAL PRODUCT DECLARATION

According ISO 14025 and EN 15804

save plastics

NIBE EXPERTS IN SUSTAINABILITY

RESULTS

Impact category	Unit	A1	A2	A3	A4	A5	B1	B2	B3	C2	C1+C3+C4	D	Total
ADPE	Kg Sb	2.87E-8	2.57E-8	4.10E-7	1.90E-7	2.44E-8	0.00E+0	0.00E+0	0.00E+0	1.95E-8	1.45E-7	-5.66E-9	8.37E-7
ADPF	Kg Sb	1.03E-3	6.71E-5	2.68E-3	4.95E-4	1.51E-4	0.00E+0	0.00E+0	0.00E+0	5.08E-5	8.92E-4	-1.80E-4	5.19E-3
GWP	Kg CO2 Equiv.	6.49E-2	9.06E-3	3.72E-1	6.69E-2	2.02E-2	0.00E+0	0.00E+0	0.00E+0	6.87E-3	1.75E-1	-2.18E-2	6.93E-1
ODP	Kg CFC-11 Equiv.	5.45E-9	1.70E-9	2.37E-8	1.25E-8	1.55E-9	0.00E+0	0.00E+0	0.00E+0	1.28E-9	9.22E-9	-2.02E-9	5.34E-8
POCP	Kg Ethene Equiv.	7.34E-5	5.48E-6	5.83E-5	4.05E-5	5.97E-6	0.00E+0	0.00E+0	0.00E+0	4.15E-6	2.09E-5	-3.73E-6	2.05E-4
AP	Kg SO2 Equiv.	2.54E-4	4.01E-5	6.14E-4	2.96E-4	4.28E-5	0.00E+0	0.00E+0	0.00E+0	3.04E-5	2.20E-4	-2.88E-5	1.47E-3
EP	Kg PO43- Equiv.	1.96E-5	7.88E-6	1.99E-4	5.82E-5	1.06E-5	0.00E+0	0.00E+0	0.00E+0	5.97E-6	6.80E-5	-5.20E-6	3.64E-4
HTP	kg 1.4 DB	6.46E-3	3.93E-3	5.56E-2	2.90E-2	3.52E-3	0.00E+0	0.00E+0	0.00E+0	2.98E-3	2.16E-2	-2.21E-3	1.21E-1
FAETP	kg 1.4 DB	2.18E-4	1.16E-4	1.48E-3	8.54E-4	1.02E-4	0.00E+0	0.00E+0	0.00E+0	8.77E-5	7.12E-4	-6.15E-5	3.51E-3
MAETP	kg 1.4 DB	6.33E-1	4.39E-1	5.57E+0	3.24E+0	3.73E-1	0.00E+0	0.00E+0	0.00E+0	3.33E-1	2.48E+0	-2.54E-1	1.28E+1
TETP	kg 1.4 DB	4.46E-5	3.14E-5	2.30E-3	2.32E-4	1.01E-4	0.00E+0	0.00E+0	0.00E+0	2.38E-5	7.80E-4	-3.85E-5	3.47E-3
Parameter	**Unit**	**A1**	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**C2**	**C1+C3+C4**	**D**	**Total**
PERE	MJ	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
PERM	MJ	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
PERT	MJ	3.52E-2	1.93E-3	6.61E-1	1.43E-2	2.61E-2	0.00E+0	0.00E+0	0.00E+0	1.47E-3	2.19E-1	-6.30E-2	8.96E-1
PENRE	MJ	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
PENRM	MJ	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
PENRT	MJ	2.44E+0	1.50E-1	5.62E+0	1.11E+0	3.28E-1	0.00E+0	0.00E+0	0.00E+0	1.14E-1	1.87E+0	-3.68E-1	1.13E+1
SM	Kg	9.70E-1	0.00E+0	0.00E+0	0.00E+0	2.91E-2	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	9.99E-1
RSF	MJ	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
NRSF	MJ	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
FW	M3	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
HWD	Kg	3.18E-6	1.05E-6	3.72E-5	7.74E-6	1.83E-6	0.00E+0	0.00E+0	0.00E+0	7.94E-7	1.24E-5	-1.36E-6	6.28E-5
NHWD	Kg	9.88E-4	8.55E-3	1.51E-2	6.31E-2	3.14E-3	0.00E+0	0.00E+0	0.00E+0	6.47E-3	1.10E-2	-6.67E-4	1.08E-1
RWD	Kg	3.06E-6	9.64E-7	2.05E-5	7.12E-6	1.16E-6	0.00E+0	0.00E+0	0.00E+0	7.31E-7	6.82E-6	-6.79E-7	3.97E-5
CRU	Kg	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
MFR	Kg	0.00E+0	0.00E+0	0.00E+0	0.00E+0	2.93E-2	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	9.75E-1	1.00E+0
MER	Kg	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0
EE	MJ	0.00E+0	0.00E+0	0.00E+0	0.00E+0	6.76E-3	0.00E+0	0.00E+0	0.00E+0	0.00E+0	0.00E+0	2.25E-1	2.32E-1
SP	**s€**	**s€ 0,01**	**s€ 0,00**	**s€ 0,03**	**s€ 0,01**	**s€ 0,00**	**s€ 0,00**	**s€ 0,00**	**s€ 0,00**	**s€ 0,00**	**s€ 0,01**	**s€ -0,00**	**s€ 0,06**

Impact categories: ADPE=Depletion of abiotic resources-elements | **ADPF**=Depletion of abiotic resources-fossil fuels | **GWP**=Global warming | **ODP**=Ozone layer depletion | **POCP**=Photochemical oxidants creation | **AP**=Acidification of soil and water | **EP**=Eutrophication | **HTP**=Human toxicity | **FAETP**=Ecotoxicity. fresh water | **MAETP**=Ecotoxicity. marine water (MAETP) | **TETP**=Ecotoxicity. terrestric

Parameters: PERE=renewable primary energy ex. raw materials | **PERM**=renewable primary energy used as raw materials | **PERT**=renewable primary energy total | **PENRE**=non-renewable primary energy ex. raw materials | **PENRM**=non-renewable primary energy used as raw materials | **PENRT**=non-renewable primary energy total | **SM**=use of secondary material | **RSF**=use of renewable secondary fuels | **NRSF**=use of non-renewable secondary fuels | **FW**=use of net fresh water | **HWD**=hazardous waste disposed | **NHWD**=non hazardous waste disposed | **RWD**=radioactive waste disposed | **CRU**=Components for re-use | **MFR**=Materials for recycling | **MER**=Materials for energy recovery | **EE**=Exported energy

ADDITIONAL INFORMATION

Allocation

Environmental profile	Explanation of used allocation method
plastics (via residue) - D	Allocation based on economic values. The output side is assumed to be 5% recycling. The EcoInvent process 'Polyethene, low density, granulate {RER} | production | Alloc Rec, U' is assumed to be the avoided environmental impact. Emissions, fresh water use, Shreddering, sorting, separation metal, cyclone, agglomerator, extrusion, purification and granulating are included. A lost of 10% is included
Save Plastics C3+C4	Economic allocation is used. 25% of energy use is allocated to C3 Waste Processing
Secondary raw material, Economic allocation = 0	Waste material has no economic value and therefore economic allocation is €0,00

Back

Appendix L

PEOPLE'S PAVILION

by Pretty Plastic

SKIN

Fire resistance

Insulation

Information

Location:	Eindhoven, Netherlands
Year:	2017
Program:	Pavilion
Building material:	recycled PVC
Size:	400 x 300 x 290 mm
Weight:	1.1 kg (per tile)

The Pretty Plastic Plant produced more than a thousand unique tiles, that were used for exclusive interior design projects. This success lead to an even greater challenge: the design for the Dutch Design Week 2017 main pavilion, the People's Pavilion.

The cladding of the facade consisted of 9.000 unique plastic upcycled tiles, all made from resident's household plastic waste. Intrigued by the beauty of the Pretty Plastic Plant, the Belgium recycling company Govaplast offered to engineer the production. They soon became Pretty Plastic's production partner.

Source:
https://www.prettyplastic.nl/tile/
https://www.archdaily.com/915977/peoples-pavilion-bureau-sla-plus-overtreders-w

Back

Appendix M

MUSIC PAVILION

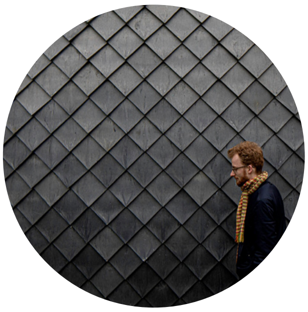
by Pretty Plastic

SKIN

Fire resistance | Insulation

Information

Location:	Oosterhout, Netherlands
Year:	2020
Program:	Education
Building material:	recycled PVC
Size:	400 x 300 x 290 mm
Weight:	1.1 kg (per tile)



A new range of facade cladding tiles made of recycled PVC construction waste, designed by Dutch studios Overtreders W and Bureau SLA, has been used on a permanent building for the first time.

The first permanent building to be clad in the hanging tiles, a school music pavilion in the Netherlands, was completed by Dutch studio Grosfeld Bekkers Van der Velde Architecten in January.

Grey diamond-shaped shingles are made from shredded PVC building products such as window frames, downspouts and rain gutters. They are hung in overlapping rows from a single screw.

First developed in 2017, the tiles received fire approval in class B (very difficult to burn) last year, allowing them to be used as a cladding material on external facades.

Source:
https://www.prettyplastic.nl/tile/
https://www.dezeen.com/2020/03/03/pretty-plastic-overtreders-w-bureau-sla-upcycled-products//

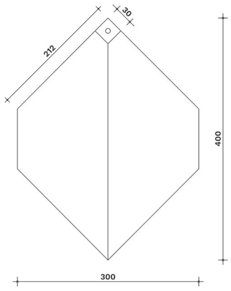
Back

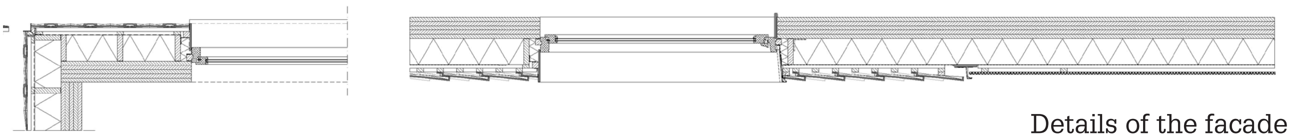
Appendix M

PEOPLE'S PAVILION & MUSIC PAVILION

Product sheet of Pretty Plastic

SKIN

TECHNICAL DATA  	Height: 400 mm Width: 304 mm Thickness: 29 mm Weight per piece: 1.100g Weight per m²: 24,4 kg Material: Recycled Polyvinylchlorid (PVC) Manufacture at: JPI Polymers Flammability (EN 13501-1:2018): Class B-s3,d0 Production tolerances: +/-2%
INSTALLATION	PrettyPlastic tiles should be attached to a wall with an underlying wooden structure made out of wooden slats (C18) with a min. dimension of 24x48m. Every tile needs one screw to be installed on the wall. The screws to be used should be SPAX-Universal Screw 25x4mm or any similiar product. Between tiles should be a space of 2mm.
WORKING POSSIBILITIES	PrettyPlastic can be sawed or drilled into without any splinters
MAINTENANCE	PrettyPlastic doesn't need any maintenance. It can be cleaned with household cleaning products.
COLOR	PrettyPlastic can be ordered in lighter or darker shades. Colors shown are always examples to give an impression. Due to the natural qualitites of recycled materials the delivered product will differ slightly in color and finish.



Details of the facade

Source:
https://www.prettyplastic.nl/tile/#product-information

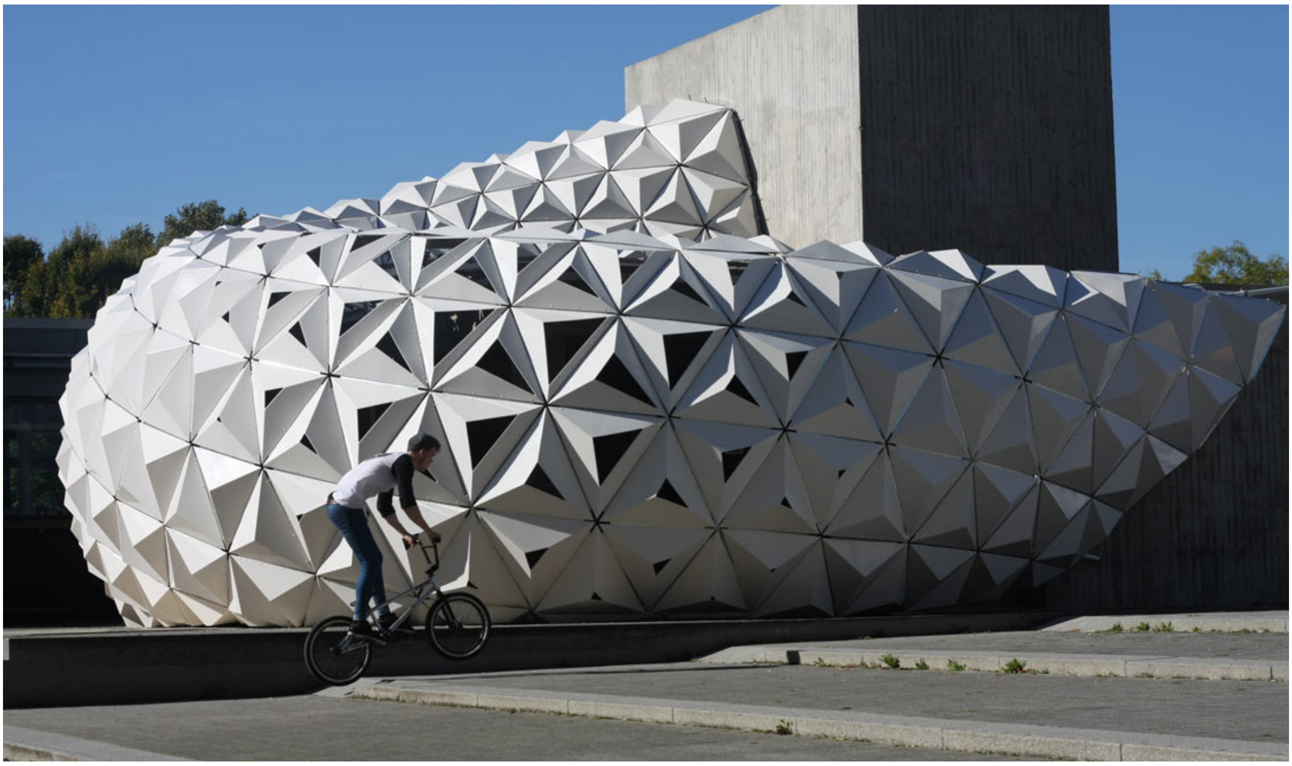
Back

Appendix N

ARBOSKIN PAVILION

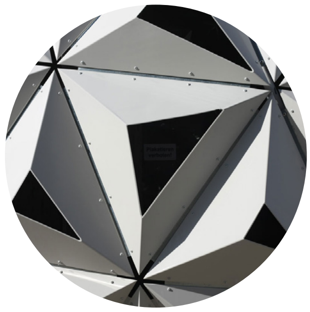
by Stuttgart University's ITKE

SKIN



Information

Location:	Stuttgart, Germany
Year:	2013
Program:	Pavilion
Building material:	Bioplastic
Size:	-
Weight:	-



Students and professors from Stuttgart University's ITKE (Institute of Building Structures and Structural Design) designed the freeform facade to demonstrate the structural properties of a new bioplastic developed specially for use in the construction industry.

Bioplastics are plastics made from renewable biomass sources such as starches, cellulose or other biopolymers, that offer sustainable alternatives to plastics derived from fossil fuels. The bioplastic used in the ArboSkin project is called Arboblend and is produced by German firm, Tecnaro, by combining different biopolymers such as lignin – a by-product of the wood pulping process – with natural reinforcing fibres.

Source:
https://www.dezeen.com/2013/11/09/arboskin-spiky-pavilion-with-facademade-from-bioplastics-by-itke/
https://omnexus.specialchem.com/product/t-tecnaro-arboblend-v5

Appendix N

ARBOSKIN PAVILION

Information of ArboSkin pavilion

SKIN

Fire resistance

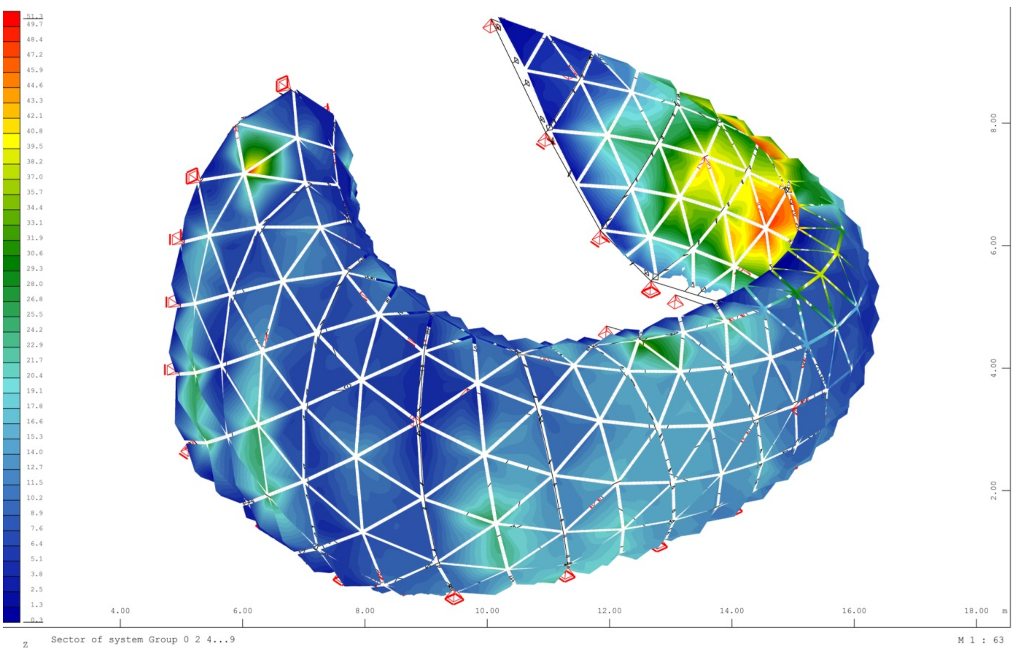
Stable structure

Mock-Up Data:

location:	Keplerstr. 11-17/ Unicampus Stadtmitte
date of completion:	October 2013
area of facade:	145m²
Material:	biobased thermoplast (equipped with flame retardants) made from >90% renewable resources
Building:	escape stairwell of lecture hall M17.02

Mechanical Properties (Arboblend V5 by Tecnaro)

	Value	Units	Test Method / Conditions
Tensile Modulus	1530.0	MPa	ISO 527
Yield Stress	26.2	MPa	ISO 527
Yield Strain	2.53	%	ISO 527
Stress At Break	22.1	MPa	ISO 527
Strain At Break	10.0	%	ISO 527
Charpy Impact Strength (+23°C)	N	kJ/m²	ISO 179/1eU



4 FE-Model Wind and snow loads

Appendix O

STRUCTURE

PLASTIC HOUSE

by Conceptos Plasticos

Fire resistance Insulation Shockproof

Information

Location:	Colombia
Year:	2015
Program:	Housing
Building material:	recyceld HDPE
Size:	530 x 130 x 70 mm
Weight:	-

everyday, bogotá, colombia, sees 740 tons of plastic waste that could take around 300 years to degrade and we're quite sure the situation is the same in different parts of the world. thankfully, a start up in colombia is trying to mitigate the negative environmental impact of waste plastic by transforming it into an alternative construction material. created by fernando llanos and architect oscar mendez, conceptos plásticos is based on the transformation of plastic residues and rubber in pieces like blocks, which are used for housing construction.

'The objective of plastic concepts is to answer to different problematic that affect the community nowadays, contributing at the same time with the reduction of the pollution that plastic residues have on the environment and his incident on the global warming,' said ricardo rico, business manager, conceptos plásticos.

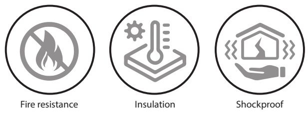
Source:
https://jdcomposites.ca/portfolio/eco-house/
https://www.saltwire.com/atlantic-canada/communities/jd-composites-going-strong-after-turning-millions-of-recycled-plastic-bottles-into-housing-100631793/

Appendix O

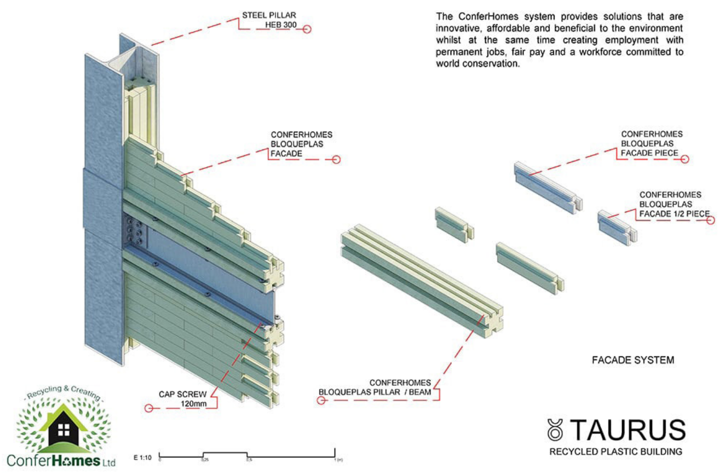
PLASTIC HOUSE

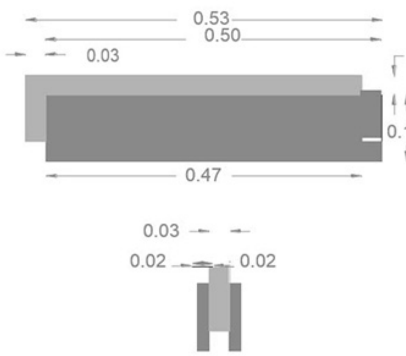
Product sheet of Bloqueplas

STRUCTURE



Product description	Bloqueplas is an interlocking wall system of stackable tongue and groove block units manufactured and distributed by Grupo Ecoplasso in Colombia. The blocks are made of recycled polyethylene terephthalate (PET), and require only a hammer to assemble a structure.
Distributors/implementing organizations	Grupo Ecoplasso in Colombia and Mexico
Market suggested retail price	~4.60 USD (15.000.000 COP) for a 40 m² house (converted on June 2019)
Unit dimensions (cm)	53 cm x 13 cm x 7 cm
Primary materials	Recycled polyethylene terephthalate (PET)
Fire Resistance (hr)	The manufacturer declares the product is fireproof
Thermal Insulation Capacity	Manufacturer informs that the material and chemical composition of the blocks become insulators of cold and heat, keeping the interior of the building at a constant average temperature. Its strong grip creates a natural barrier against noise, water, and wind
Compressive Strength (MPa)	200 MPa
Lifecycle	The manufacturer claims that plastics take over 500 years to biodegrade and therefore the homes could last for many generations.
Manufacturer specified performance targets	High insulating value, durability (protecting from noise, water, wind, insects, and pathogens), earthquake resistance, and quick construction.
Complementary technical systems	Electricity, sanitation, and water infrastructure are required.





Source:
https://www.engineeringforchange.org/solutions/product/bloqueplas-2/
https://www.basilioparedes.com/en/proyectos/arquitectura-residencial/taurus-viviendas-plastico-reciclado/

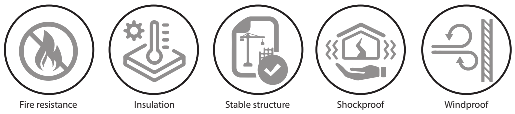
Back

Appendix P

STRUCTURE

RECYCLED HOUSE

by JD Composites



Information

Location: Nova Scotia, Canada
Year: 2009
Program: Housing
Building material: recyceld PET bottles
Size: 185 m^2
Weight: -

This innovative and eco-friendly new concept home out-performs traditional construction in several ways: it is strong enough to withstand Category 5 hurricane winds; it has minimal maintenance requirements; its energy efficiency ratings are in the upper levels on the energy guide; costs are similar to those for conventional construction of the same size; homeowners significantly save in long-term costs.

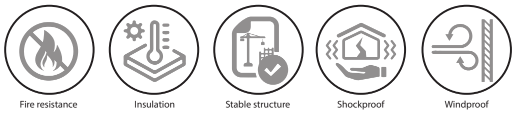
Our panel core is a closed-cell material. If something punctures the skins of the wall or roof, and humidity passes through the core, it maintains its functionality and shape. Unlike conventional materials, our panels are resistant to water and moisture absorption, which prevents the degradation of structural and insulation properties. It is truly a “lock up and leave” home that requires no maintenance during unattended periods.

Source:
https://jdcomposites.ca/portfolio/eco-house/
https://www.saltwire.com/atlantic-canada/communities/jd-composites-going-strong-after-turning-millions-of-recycled-plastic-bottles-into-housing-100631793/

RECYCLED HOUSE

Product sheet

STRUCTURE



HOMEOWNER INFORMATION SHEET

ENERGUIDE

Your EnerGuide* rating and this report are based on data collected and, where necessary, presumed from your evaluation. Rating calculations are made using standard operating conditions.

Rating: 50 gigajoules per year (GJ/year)

Heated floor area: 170.6 m² (1836.3 ft²)

Rated energy intensity: 0.30 GJ/m²/year

Evaluated by: Jim Baxter

Quality assured by: Trinity Inspection Services

File number: 5Q28D00033

Data collected: July 9, 2019

Year built: 2018

NRCan.gc.ca/myenerguide

HOW YOUR RATING IS CALCULATED:

I.	Rated annual energy consumption	50 GJ/year
II.	Minus renewable energy contribution	- 0 GJ/year
	Equals your **EnerGuide rating**	**= 50 GJ/year**

I. Your rated annual energy consumption is the total amount of energy your house would use in a year based on the EnerGuide Rating System standard operating conditions. For your house, this includes 10.85 GJ of passive solar gain.

Energy Sources	Rated Consumption (GJ/year)	Equivalent Units (per year)	Greenhouse Gas Emissions (tonnes/year)
Electricity	50	14008kWh	10.3
Total	50		10.3

II. On-site renewable power generation systems can offset some or even all of your home's energy consumption. Renewable energy contributions are factored differently for your rating and your greenhouse gas emissions calculations.[1]

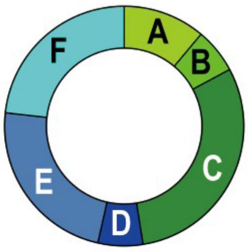
On-Site Renewable Energy	Estimated Contribution (GJ/year)	Equivalent Units (per year)	Offset Greenhouse Gas Emissions (tonnes/year)
Electricity	0	0 kWh	0.0
Solar water heating	0	0	0.0
Total	0		0.0

YOUR RATED GREENHOUSE GAS EMISSIONS CALCULATION:

Total greenhouse gas emissions	10.3 tonnes/year
Minus emissions offset by on-site renewables	- 0.0 tonnes/year
Equals your **rated greenhouse gas emissions**	**= 10.3 tonnes/year**

HOW YOUR RATED ENERGY IS USED:

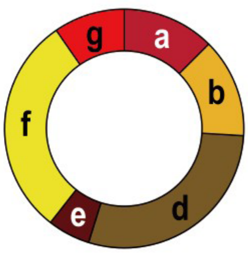
The chart below represents the breakdown of rated annual energy consumption in your home under standard operating conditions. You can use these figures as a guide to help identify where you can lower home energy costs through proper home maintenance, efficient home operation, energy efficiency renovations or equipment replacement.



- A. Space heating 11%
- B. Space cooling 5%
- C. Water heating 30%
- D. Ventilation 3%
- E. Lights & appliances 23%
- F. Other electrical 28%

WHERE YOUR HOME LOSES HEAT:

Houses lose heat through their exterior shell, or building envelope. The chart below shows where and how your home loses heat. The quality and upkeep of your home can have a major impact on the amount of energy your heating and cooling systems use annually.



- a. Attic/Ceiling 13%
- b. Main Walls 14%
- c. Exposed floors 0%
- d. Windows 30%
- e. Exterior doors 2%
- f. Basement/Foundation 31%
- g. Air leakage/ventilation 10%

*EnerGuide is an official mark of Natural Resources Canada.
Refer to the glossary section for an explanation of relevant terms.

Back

RECYCLED HOUSE

Product sheet

STRUCTURE

Fire resistance | Insulation | Stable structure | Shockproof | Windproof

HOUSE DETAILS

BUILDING ENVELOPE

ATTIC/CEILING

TYPE	INSULATION VALUE		AREA m² (ft²)
	Nominal RSI (R)	Effective RSI (R)	
Ceiling01: Cathedral	8.54 (48.5)	8.40 (47.7)	170.6 (1836)

MAIN WALLS

TYPE	INSULATION VALUE		AREA m² (ft²)
	Nominal RSI (R)	Effective RSI (R)	
Main floor	5.53 (31.4)	6.02 (34.2)	145.1 (1562)

WINDOWS

#	TYPE	U-factor W/m² • °C (Btu/h • ft² • °F)	RSI (R)
1	Vinyl, Fixed, Triple, Low E	2.4 (0.43)	0.41 (2.3)
1	Vinyl, Hinged, Triple, Low E	2.3 (0.4)	0.44 (2.5)
1	Vinyl, Fixed, Triple, Low E	2.1 (0.38)	0.47 (2.7)
2	Vinyl, Fixed, Triple, Low E	2 (0.35)	0.50 (2.8)
2	Vinyl, Fixed, Triple, Low E	2 (0.34)	0.51 (2.9)
1	Vinyl, Hinged, Triple, Low E	2 (0.34)	0.51 (2.9)
2	Vinyl, Hinged, Triple, Low E	1.7 (0.3)	0.58 (3.3)
1	Vinyl, Fixed, Triple, Low E	1.7 (0.29)	0.60 (3.4)
2	Vinyl, Hinged, Triple, Low E	1.6 (0.29)	0.61 (3.5)
1	Vinyl, Hinged, Triple, Low E	1.6 (0.28)	0.62 (3.5)
1	Vinyl, Hinged, Triple, Low E	1.4 (0.25)	0.71 (4.1)
Total window area: 22.6 m² (244 ft²)			

EXTERIOR DOORS

#	TYPE	U-factor W/m² • °C (Btu/h • ft² • °F)	RSI (R)
3	Steel medium density spray foam core	0.9 (0.15)	1.14 (6.5)
Total door area: 6.4 m² (69 ft²)			

BASEMENT/FOUNDATION

TYPE	INSULATION VALUE		AREA m² (ft²)
	Nominal RSI (R)	Effective RSI (R)	
Foundation - 1 slab	2.22 (12.6)	2.22 (12.6)	161.8 (1741)

AIRTIGHTNESS

Air leakage rate at 50 pascals	0.54 air changes/hour
Equivalent leakage area	83.1 cm² (13 in²)
Normalized leakage area	0.2 cm²/m² (0.3 in²/100 ft²)

MECHANICAL SYSTEMS

SPACE HEATING

TYPE	OUTPUT SIZE	EFFICIENCY
Electric baseboard	5 kW 17500 BTU/h	100% Steady State
Mini-split air-source heat pump	5.36 kW 18500 BTU/h	10.87HSPF
Design heating load: 4.19 kW – refer to glossary for details		

SPACE COOLING

TYPE	OUTPUT SIZE	EFFICIENCY
Mini-split air-source heat pump	5.36 kW 18500 BTU/h	20 SEER
Design cooling load: 2.17 kW		

WATER HEATING

TYPE	TANK VOLUME	EFFICIENCY
Electric storage tank	189L (50 USG)	0.82 EF

WHOLE-HOME VENTILATION

TYPE	AIR FLOW RATE	EFFICIENCY
Heat recovery ventilator certified by the Home Ventilating Institute	70.79 L/s (150 cfm)	60%

HEATED FLOOR AREA

Above-grade area	170.6 m² (1836.3 ft²)
Below-grade area	0 m² (0 ft²)

Appendix P

RECYCLED HOUSE

Product sheet

STRUCTURE

Fire resistance | Insulation | Stable structure | Shockproof | Windproof

39 Sunset Lane,
Meteghan River, NOVA SCOTIA, B0W 2L0

ENERGUIDE

Data collected: July 9, 2019
File number: **5Q28D00033**
Evaluated by: Jim Baxter

50 This House **GJ/year**

0 GJ/year — Best energy performance

83 GJ/year — A typical new house

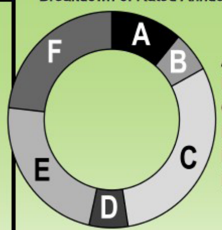
Uses most energy

One gigajoule (GJ) equals the energy from two BBQ propane tanks

Rated Annual Energy Consumption		50 GJ
• Electricity	50	
On-site renewable energy contributions		- 0 GJ
• Electricity	0	
• Solar water heating	0	
EnerGuide Rating:		= 50 GJ

Figures may not add up due to rounding.

Breakdown of Rated Annual Energy Consumption:



A	Space heating	11%
B	Space cooling	5%
C	Water heating	30%
D	Ventilation	3%
E	Lights & appliances	23%
F	Other electrical	28%

Rated Energy Intensity: **0.30 GJ/m²/year**

Rated Greenhouse Gas Emissions: **10.3 tonnes/year**

The energy consumption indicated on your utility bills may be higher or lower than your EnerGuide rating. This is because standard assumptions have been made regarding how many people live in your house and how the home is operated. Your rating is based on the condition of your house on the day it was evaluated.

Quality assured by: Trinity Inspection Services

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Canada

NEXT STEPS

If you have had a Renovation Upgrade Service, refer to your report for the roadmap to making your home more energy efficient. If you have not yet had a Renovation Upgrade Service, why not contact your service organization to learn what you can do to save on energy costs, reduce greenhouse gas emissions and improve home comfort?

Everyone uses energy in their house differently. This report was developed using standard operating conditions as explained in the glossary. Therefore, your EnerGuide rating will not match your utility bills.

UPGRADE CONSIDERATIONS

Before undertaking upgrades or renovations, find out about appropriate products and installation techniques, and ensure that all renovations meet local building codes and by-laws. Natural Resources Canada does not endorse the services of any contractor, nor any specific product, and accepts no liability in the selection of materials, products, contractors nor performance of workmanship.

Where your energy advisor has identified a potential health or safety concern such as insufficient outdoor air, risk of combustion fumes entering your house or risk of exposure to asbestos, they have endeavoured to provide a warning in this report. However, energy advisors are not required to have expertise in health and safety matters, and homeowners are solely responsible for consulting a qualified professional to determine potential hazards before undertaking any upgrades or renovations.

Visit us today at:

Back

Appendix Q

3D PRINT CANAL HOUSE

by DUS Architects

STRUCTURE

Fire resistance Insulation Stable structure

Information

Location:	Amsterdam, Netherlands
Year:	2015
Program:	Prototype
Building material:	Bio-plastic mix
Size:	2200 x 2200 x 3500 mm
Weight:	180 kg (total)

Originally launching in early 2014 at an expo-site in Amsterdam North, Amsterdam based DUS architects and contributing partners have made the 13 room project reality. To fabricate 3D printing in a larger scale for a 8 square-meter house the team developed a jumbo size printer named 'KamerMaker', printing matter up to 2 x 2 x 3,5 meters. The canal house will be open to public until 2017.

The design plays with the relations between indoor and outdoor spaces creating luxury within a minimum footprint. Entirely 3D printed with black colored bio-based material it showcases different types of façade ornament, form-optimization techniques and smart solutions for insulation and material consumption.

Source:
https://houseofdus.com/project/3d-print-canal-house/
https://www.archdaily.com/794855/urban-cabin-dus-architects
http://www.allthings.bio/3d-printed-bioplastic-the-future-of-construction/

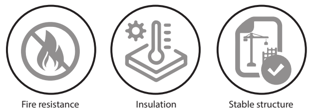
Back

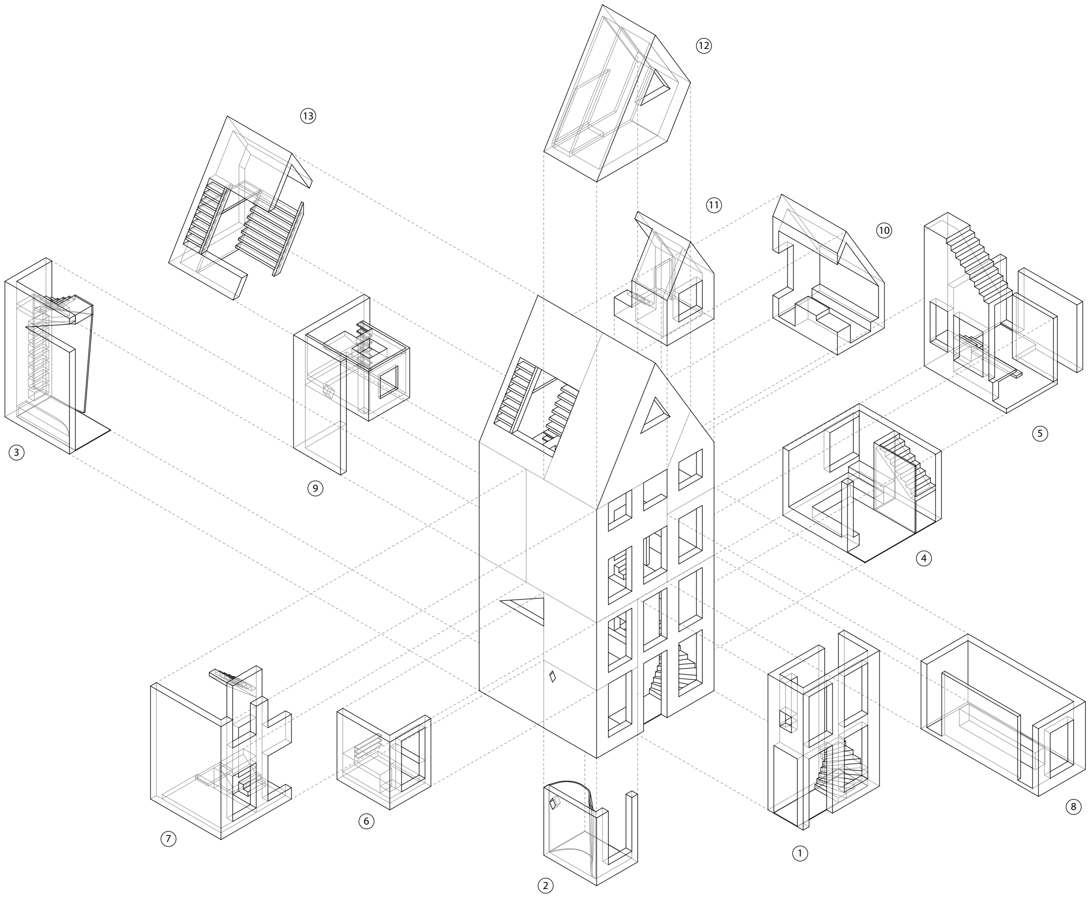
Appendix Q

3D PRINT CANAL HOUSE

Original design

STRUCTURE





1 SMART ROOM ENTRANCE
2 RAIN ROOM TOILET
3 LIBRARY ROOM STUDY
4 POLICY ROOM LIVING
5 RECYCLING ROOM DINING
6 POTATO ROOM KITCHEN
7 CONSTRUCTION ROOM OFFICE
7 WORKSHOP ROOM MEETING
8 SOFT ROOM HOTEL
9 DOWNLOAD ROOM MINI BAR
10 GLOBAL ROOM GUESTS
11 MATERIAL ROOM SPA
13 POP-UP ROOM GARDEN

Back

Appendix R

R-IGLO PAVILION

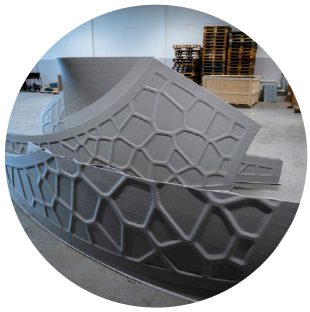
by Royal 3D

STRUCTURE

Fire resistance
Insulation
Stable structure

Information

Location:	Rotterdam, Netherlands
Year:	2020
Program:	Workspace
Building material:	recycled PET
Size:	-
Weight:	-



This sustainable property solution is named R-IGLO due to its distinctive and instantly recognisable appearance. The letter R stands for Reusable, Recycled, Rotterdam and Royal3D. The ArchiTech Company designed the shape and distinctive pattern. The structure consists of adaptable elements of different sizes. Its modular character means the individual sections are easy to transport and assemble, which also makes them easy to dismantle and store.

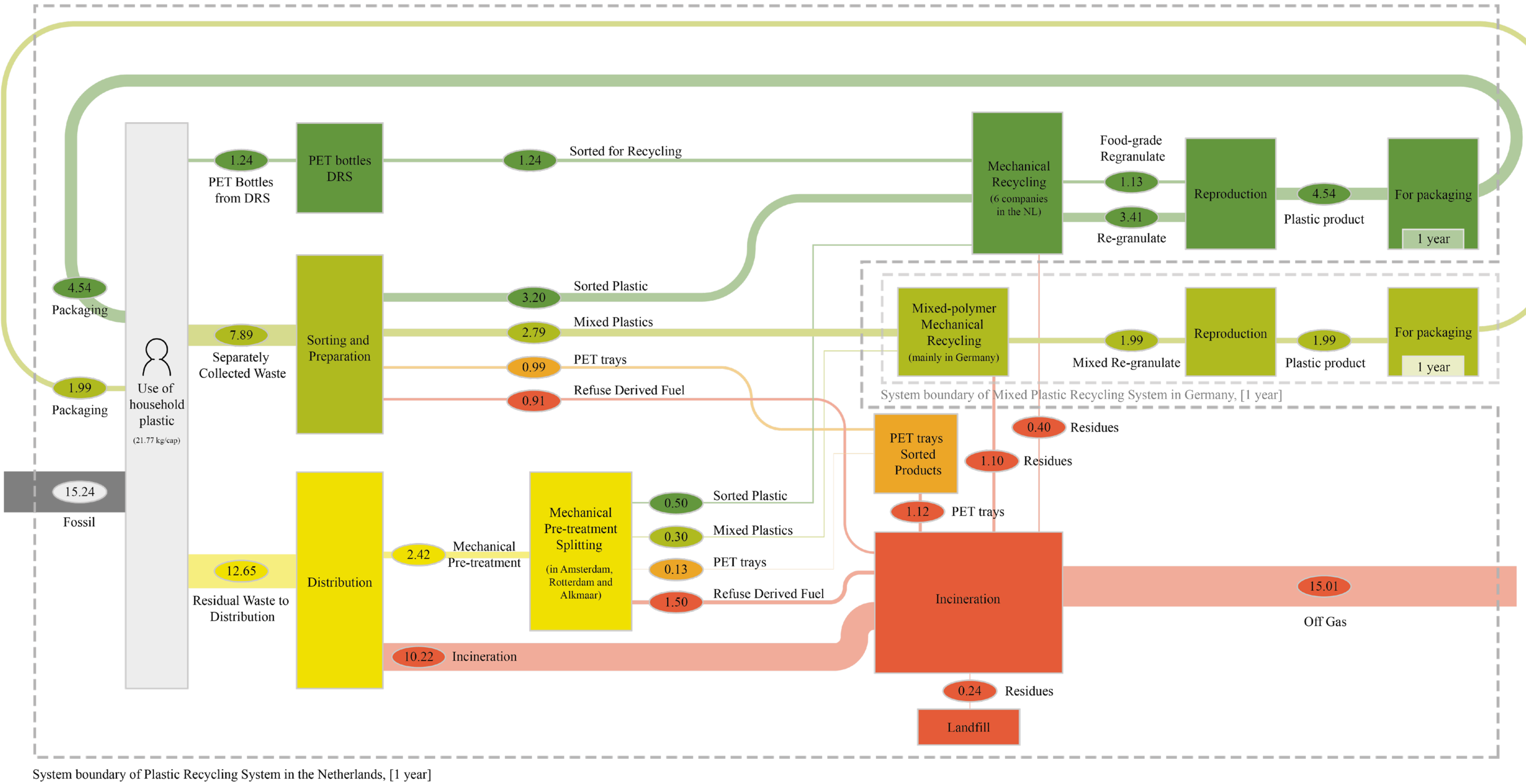
The R-IGLO is printed from recycled PETG material from the port of Rotterdam, reinforced with 30% fibreglass. Using Royal3D’s Continuous Fibre Additive Manufacturing (CFAM) printer in De Werkplaats in M4H, printing can be carried out on an industrial scale. The machine prints at least 15 kg per hour and can print objects measuring up to 4 x 2 x 1.5 metres. CFAM allows fibre to be added continuously to the print material, significantly increasing its structural strength and stiffness.

Source:
https://www.portofrotterdam.com/en/setting/location-options/property-and-plots/r-iglo
https://www.architechcompany.com/site/r-iglo-workspace-rotterdam/

Back

Appendix S

CURRENT PLASTIC FLOW IN 2017

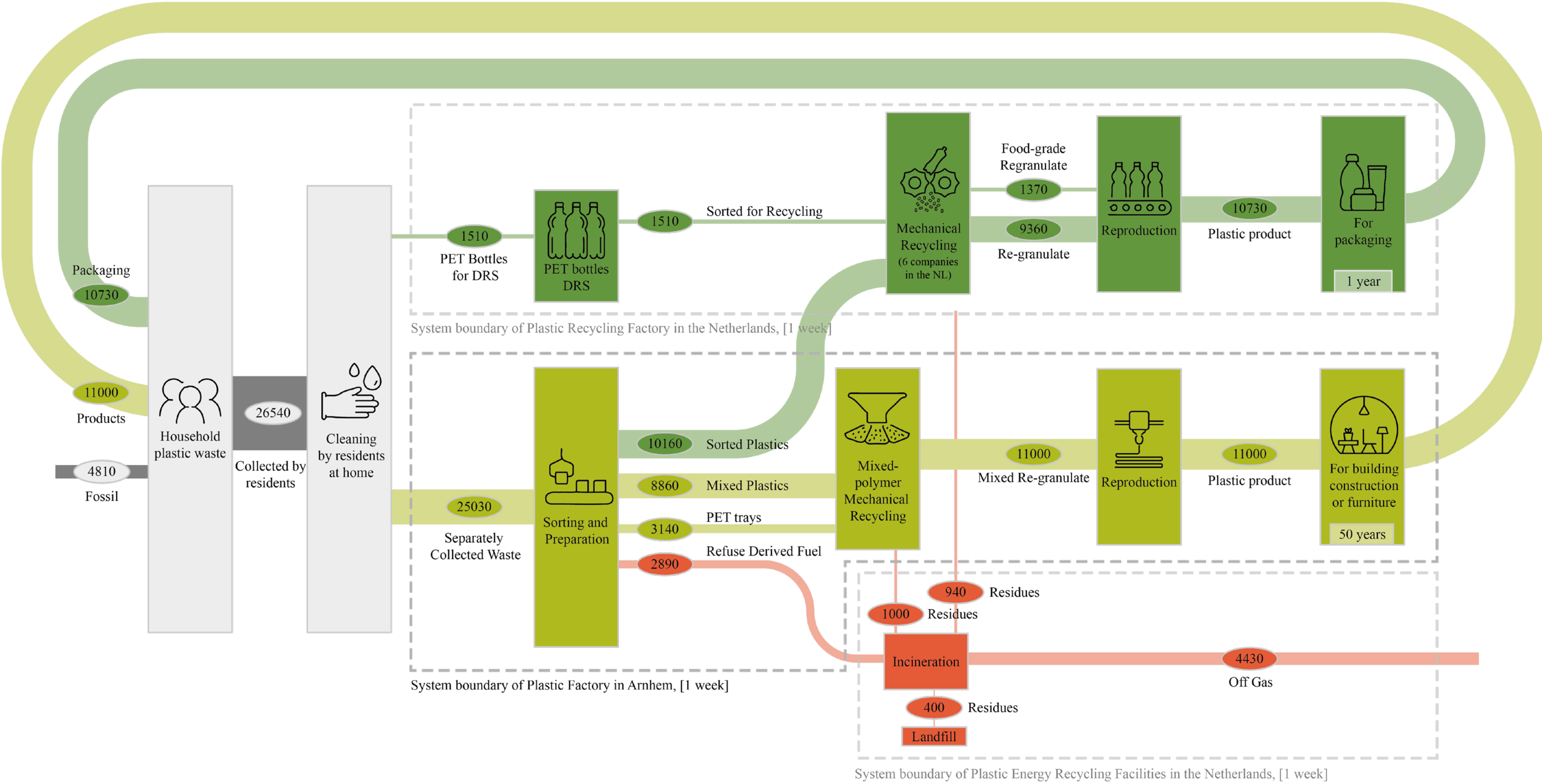


Waste packaging plastic flows from household in the Netherlands in 2017 (kg/cap)

Back

Appendix T

PROPOSED PLASTIC FLOW IN 2030



Waste packaging plastic flow for the all 58.000 residents in the North Arnhem in 2030 (kg/week)