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Interactive Anthropocene-Aware Building Envelope:

Investigating Plastiglomerate as a Semi-Synthetic Building Material

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The Anthropocene is an epoch where there are more trees growing in farms than in the wild, where more rock and soil is moved by bulldozers and mining than all 'natural' processes combined and where the climate is tipping out of control due to the burning of oil, gas, and coal. Industrial capitalism is irreversibly altering the natural cycles of the biosphere, nature is now a product of culture. It is no longer just asteroid impacts and volcanic eruptions that herald mass extinctions, it is us, the 20% of the world that is consuming 80% of its resources. (Grindon, G., 2014).

Hello

Abstract

Plastiglomerate is the first physical marker inscribed in the geological record, forever indicating our presence, called the Anthropocene era. The human species have only recently been aware of the gravitude our impact has on climate change, on a global scale. Nonetheless, this awareness is until now only limited to conferences and promises. People have yet to change their habits, and demand for action.

In order to mitigate this existential issue, this thesis investigates the use of Plastiglomerate as an experiential novel material in architecture as a means of awareness. It is made through a rainscreen application on an impactful existing building in Turin.

Progressively, this thesis studies the implications that proposition entails. The foundations are set by defining the Anthropocene as a Hyperobject, a term first coined in 2008 (Morton, T., 2013), hence categorizing the Anthropocene as a topic of immense scale that is difficultly grasped. The position of consciousness is then discussed ranging from our daily practices to major wonderment.

Artists acting as activists have always been at the forefront of exacerbating engagement with the viewer. Therefore, the different means design could radiate awarness on this topic is studied. Following the artists, architects express their concerns and use different tools and techniques through design philosophies, and experimental material uses; notably at the envelope level.

An extensive research is done on plastic properties as a building material. This is followed by two scientific case studies of plastic waste-based composite materials, solving specific regional or global issues, such as the scarcity of sand used in the construction field and reusing landfill bound plastics.

With Plastiglomerate being a locally supplied material, Turin's plastic waste is inspected within Italy's plastic waste stream. Therefore, the quantity and type of un-recycled plastic that would be saved to create the heterogeneous material is estimated.

The Material Driven Design (MDD) method created by Karana, E. et al, (2015) is a tool for creating new materials' vision, not only considering their functional use, but aknowledging their experiential importance. With this process can emerge Plastiglomerate's intended goals and considerations for the prospective rainscreen. The method also entails a comprehensive observation of previous designers' experiences with this material.

Finally, these considerations culminate in a hypothetical application of the Plastiglomerate rainscreen on the Torre Littoria located in the heart of the city of Turin, via a ventilated facade system application.

Issues:

I. Turin is one of the most polluted cities in Europe, although some initiatives have been taken, they are mostly only presented by big actors, institutions, and governmental regulations.

II. The cities across time have lost the true notion of integrating nature. We only talk about green spaces and not nature, these spaces are only designed for humans.

III. The creation of Plastiglomerate formed in the beaches all over the world where plastic waste is being mixed with sand and gravel. This new semi-synthetic material is a consequence of human activities. It is a direct marker of the Anthropocene.

Responses:

I. The thesis wants to investigate and propose a way to tackle the issue of awareness of the human impact in the environment (Anthropocene) through an interactive building envelope; to engage the general population of Turin.

II. Biophilic design that not only takes into consideration humans, but other living residents of the city.

III. Investigating how to make use of Plastiglomerate as a building material in Architecture.

Key Words: Anthropocene, Awareness, Hyperobjects, Plastiglomerate, Interactive Envelope, Biophilic Design, Design for Disassembly, Rainscreen, Experiential Building Material, Fine Recyled Aggregates, Construction and Demolition Waste.

Contents

1. Anthropocene

Figure 1: Coal Mine #1, North Rhine, Westphalia, Germany (2015).
© Edward Burtynsky, courtesy Nicholas Metivier Gallery, Toronto.

1.1 Definition

For the past few thousand years, human beings have lived in a geological epoch called the Holocene, known for its relatively stable and temperate climate. Unfortunately, it is coming to an end. Although, the time of origin is still debatable, some people believe that since the Industrial Revolution, we have begun to alter the Earth so extremely that, according to many scientists, a new epoch has initiated.

Anthropocene, from the Ancient Greek word anthropos, meaning "human", acknowledges that humans are the major cause of the Earth's current transformation. This geological epoch is causing: extreme weather, swamped cities, resource shortages, extinct species, dried-out lakes. The obnoxious problem is that what we do and how we act today will still have consequences in the long run. Regrettably, in our mundane daily activities regardless of being conscious or not, we are taking part as a species in the destruction of ecology. (Blasdel, A., 2017)

This epoch is not only a period of manmade disturbance. It is also a moment of revelation, of self-awareness, in which the human species is becoming conscious of itself as a planetary force. We are not only driving global warming and ecological destruction; we know that we are. Yet people still behave the way they do, or at least show traits of nonchalance. (Blasdel, A., 2017)

This awareness is not only present when politicians discuss international environmental agreements, but when we do something as common as chat about the weather, pick up a plastic bag at the market or water the plants. Increasingly, we live in a world with a moral compass that did not exist before. Tragically, in this modern consumeristic society, it is only by exploiting the planet that we have just realized how much a part of it we are.

1.2 Hyperobject

Hyperobject is a term introduced by Timothy Morton, professor, and chair in English of Rita Shea Guffey at Rice University. His work explores the intersection of object-oriented thought (which is a unique form of speculative realism and non-anthropocentric thinking) and ecological studies. Hyperobjects refer to things that are massively distributed in time and space. A hyperobject can vary from the solar system to all the aluminium found in the earth. It could be a long-lasting product manufactured by the human species, such as plastic bags or Styrofoam. They exist regardless of us thinking about them or not. (Morton, T., 2013)

Hyperobjects pose conceptual and methodological issues due to their vast scale. They are "thinkable" but not directly observable due to their geographical and temporal scale. Subsequently, we see aspects of hyperobjects interacting with other things rather than the entire object. This means that they simultaneously exist in small and wide scales, which renders their appearance "uncanny". For instance, global warming is experienced through local experiences like flooding or sunburn. All of which are manifestations of the effects of global warming. They do not encompass the entirety of what is defined as global warming. Global warming is part of a larger hyperobject that includes human waste on the planet. The inadvertent vestiges of human activity, also known as the Anthropocene.

1.3 Awareness

This uncanny position of self-knowledge illuminates and positions us in the biosphere in a way that is far less superficial than we like to think. The Anthropocene is an anti-anthropocentric concept that enables us to view our species not as a defined object that can be described and summed up simply. We now understand that our causality is bigger than us, and that it is something hard to grasp if even possible.

Climate change is slow, and we are fast. When you are racing through a rural landscape on a bullet train, it looks as if everything you are passing is standing still: people, tractors, cars on country roads. They aren't, of course. They are moving, but at a speed so slow compared to the train that they appear static. (Klein, N., 2014) The awareness of the Anthropocene is us realizing it.

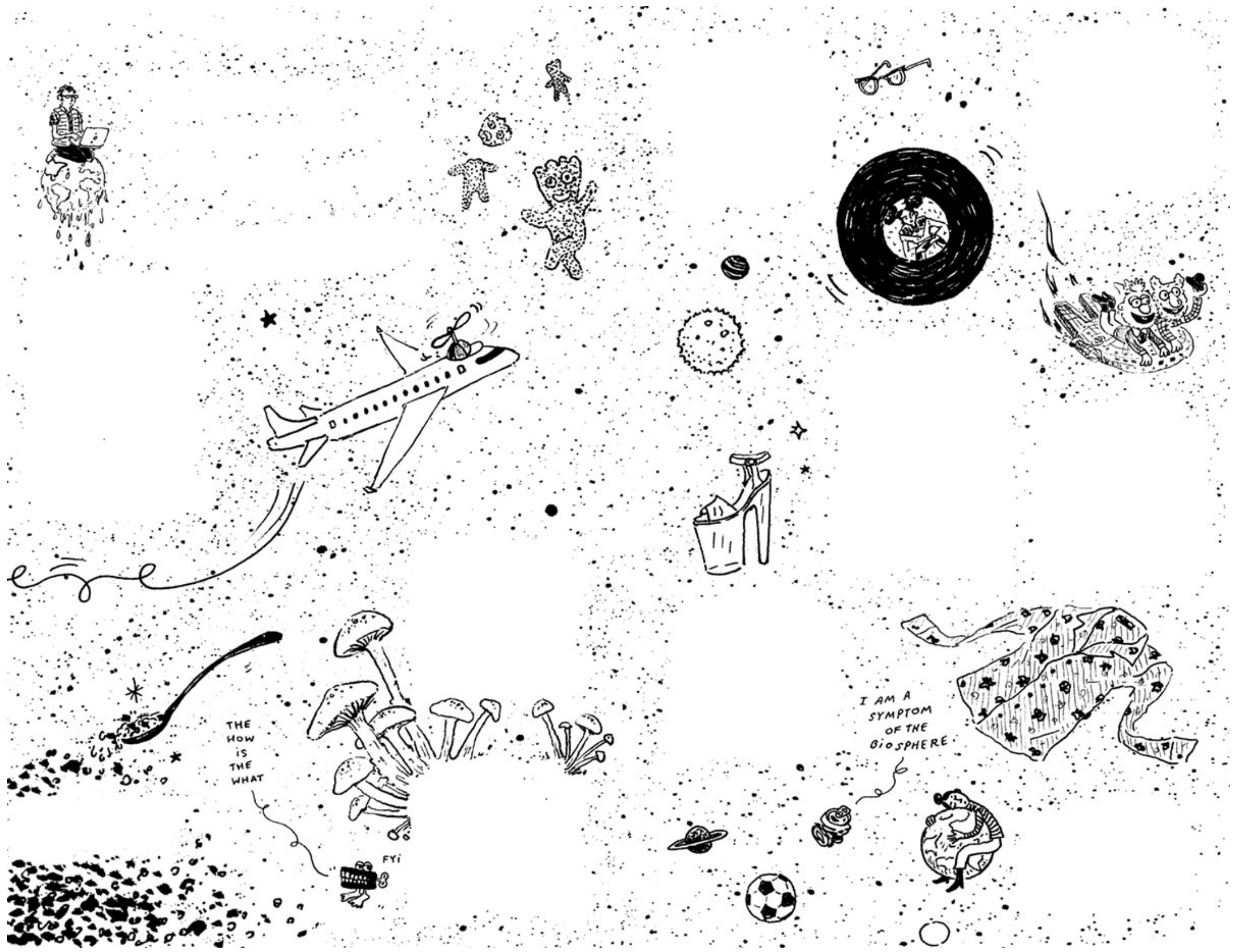


Figure 2: Ecological Philosopher Timothy Morton on Saving the World, Sour Patch Kids, and Versace Shirts.
© Joana Avillez.

2. Awareness Through Design

Figure 3: La Llareta #0308-2B31 - XXII Triennale di Milano, Broken Nature: Design Takes on Human Survival.
© Rachel Sussman.

2.1 Multi-Disciplinary

Design has always been in the forefront of expressing concerns. These manifestations come from different disciplines. Artists find ways to send a message through their art, they could either be symbolic, physical, or digital. They can be means to mirror the negative consequences of our actions.

These artists can be thought as activists trying to highlight the question of how to mobilise a collective political response, in the face of overwhelming environmental denial. They enable us to fully comprehend the scale of potential loss. Simultaneously, they give us a sense of the possible optimistic future, an ability to imagine another, less destructive way of living, therefore incite changes in action.

They have devised methods for bringing environmental issues to the public's attention. The first technique is to display the natural environment's beauty as well as the sadness linked with its loss. The second one is to show the physical and biological consequences of climate change. The third way is to portray the inhabitants' experiences. The fourth option is to create a metaphor for the presence of an "outsider" - such as a visitor, explorer, or scientist. (Michalowska, M., 2020)

2.1.1 Installations

Installations are quick and impactful, the artists make use of big events such as the Venice Biennale, to showcase their work and reach the greater population. These installations can vary in permanence, shape and medium to urge the viewers to interact with the art and get the message through.

The british sculptor Jason deCaires Taylor shown in (Figure 4) uses water as his medium, challenging the way we see our home planet and see ourselves in relation to nature. His sculptures double as artificial reefs, alerting the viewer of our negative impact on the underwater world by causing coral bleaching. The artist Taylor, J.d. (2021) explains how they are "constructed using pH-neutral materials to instigate natural growth, create new habitats [for marine life] and attract visitors away from natural fragile marine areas." As the sculptures transform into homes for living organisms, the appearance of the art changes, reflecting the dynamism of the planet. The shifting appearance of these human figures literally brings us closer to nature and reminds us that we are part of it. The progressive change in their appearance caused by the marine wildlife colonizing the surface of the sculptures could also be seen as recording devices keeping track of the pollution in the deeper level of the sea.

2.1.2 Expositions

Similar to installations, artists make use of expositions' opportunity to establish the lost contact between man and nature.

"The Room of Change" (Figure 5) is an installation made up of a sort of data tapestry, which illustrates how many aspects of our environment have changed over the past centuries, how they are still changing and how they are likely to change in the future. Combining different data sources that describe the world both from a global perspective as well as from a local and individual point of view, the installation tells stories of people and the evolution over time of their relationship with their surroundings, in a layering of dense and granular information that highlights how widespread the changes are at every scale.

The data visual is read from left to right, it covers eight distinct chapters of human interactions, that have been narrowed down to be able to chart human history from 1000 B.C. to 2400 A.D. (Nature, Universe, Animal Kingdom, Society, Hope, Happiness, Science, and Technology). However, observed vertically, the tapestry shows the interplay among interconnected forces in specific years. To repair the "broken nature" of one specific relationship, it suggests examination of our interactions with everything that we touch and that touches us. The work encourages the visitors to view the installation as possible solutions. (Lupi, G., 2019)

This exhibition illustrates how data can be used as a medium for awareness, portraying therefore the range of means that can be used as tools to inform us of our own impact, hence unpacking the hyperobject.

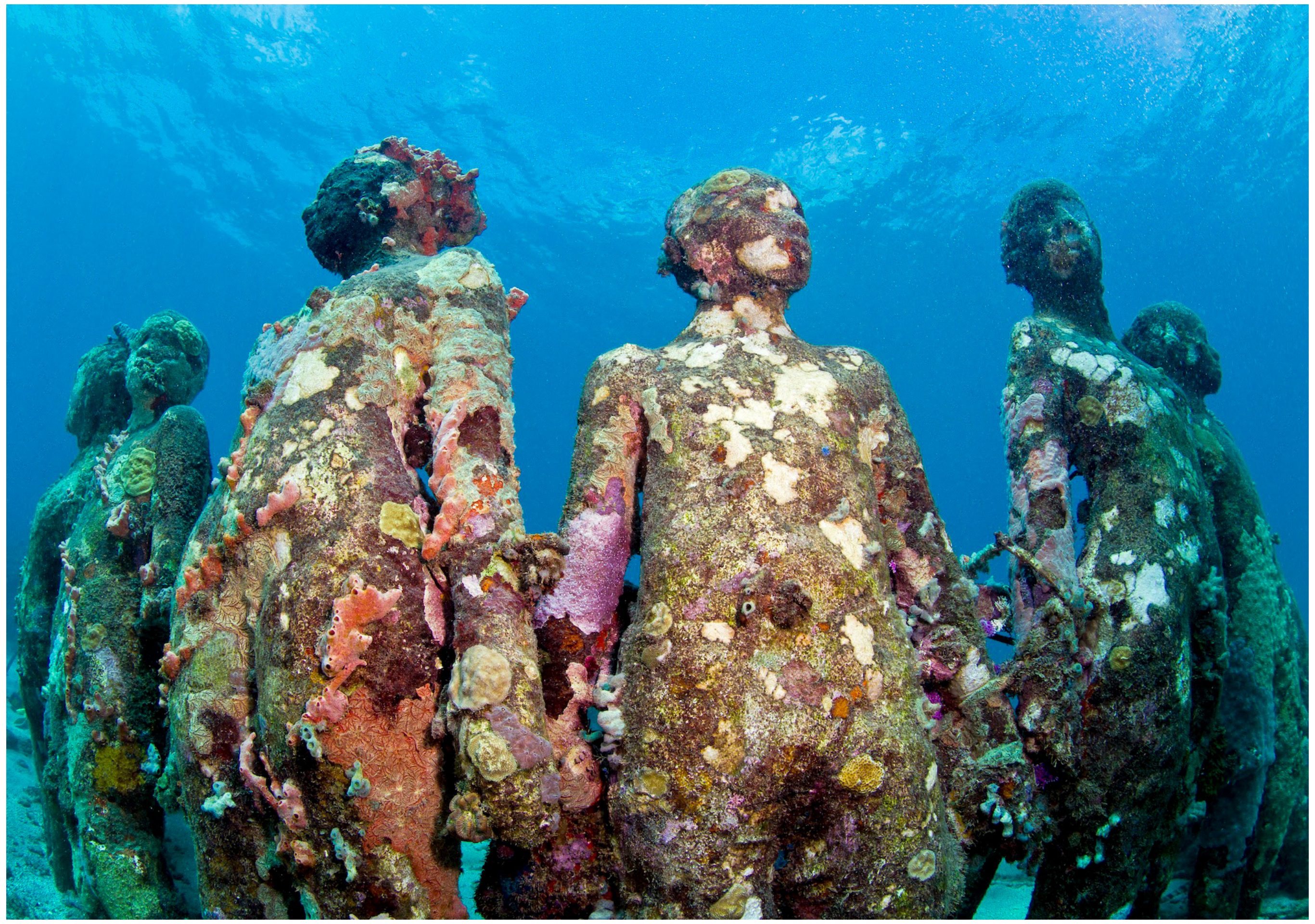


Figure 4: Underwater sculptures for the Venice Biennale 2017, become homes for marine life.
© Jason deCaires Taylor.

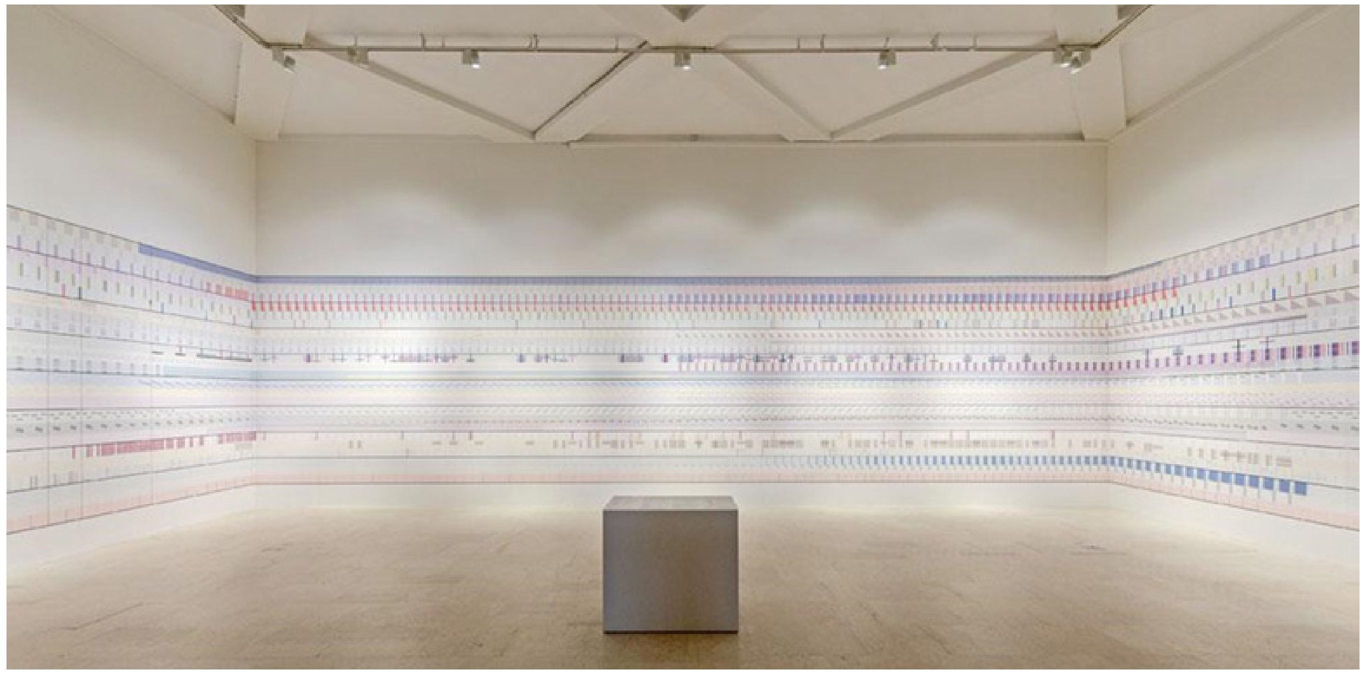


Figure 5: Accurat's "The Room of Change" at the 2019 Milan Triennale.
© Gianluca Di Ioia.

Awareness Through Design

2.2 Architecture

Architecture along with the humanities holds a certain responsibility to awaken the sense of ecological emergency in the global population. It can take multiple forms and can be transmitted through experimentation in different means: a direct visual message, a more subtle yet apparent material usage, a sensitive design philosophy considering all species in the early stages of conception, by promoting biodiversity within our cities.

The architecture discussed above is different from traditional sustainable architecture because for the most part this last one does not concern or engage the average citizen. I say that not to be only critical about it, because I acknowledge its importance, however what I do find lacking is the dialogue sustainable architecture should have with the citizen about the pressing hyperobject of the Anthropocene.

The following examples of architecture would differ from the traditional sustainable architecture by not only focusing on the scientific side of it, or the energy consumption that the building needs. However, it would rather highlight a more experimental or philosophical connotation and more importantly have a drawing message to address.

2.2.1 Digital Screens

In our image-oriented era, digital screens could be used on façades of buildings in the city to inform their citizens with direct alarming messages about climate change. This medium is very effective, because the information showcased is straightforward. Nowadays, people are very accustomed to seeing screens on their phones or personal electronics but are not used to seeing important information on screens displayed on building facades. Therefore, the information shown would stick in people's conscience due to the unusual experience.

The Climate Clock in New York City (Figure 6) informs its citizens of the time we have left to limit global warming to 1.5°C. The Climate Clock team has decided to show a glimpse of hope to encourage action against climate change. Now, an additional clock named the Lifeline; shows the percentage of the world's energy sourced from renewables. (Moynihan, C., 2021)

2.2.2 Design for Biodiversity

Biodiversity can be defined by three scales; the first one being the largest, habitats such as wetlands, forests, coral reefs, the second one, a smaller scale, concerns the variety of individual species: salmons, hyenas and ants. Finally, the last one is more meticulous and looks at the differences between the same species, it concerns the genetic varieties. (Edwards, B., 2010)

Climate change and biodiversity when thought in the design process to be intertwined; generates a new meaning of sustainable architecture - one that promises more depth and beauty than buildings merely reducing their carbon footprints.

Herein, it would be wise to look at biodiversity at a larger scale, using the tools we have as architects to analyse the opportunities and challenges at an urban scale to understand the interdependencies that come in play when studying the impact our footprint has on biodiversity. Practically, if we took a building in Turin as a case study, research would be done on all types of species crossing the city, for example we would look at Pallid Swifts (Apus Pallidus) migration trajectory. We would understand if and how we are impacting it, we would then ask ourselves if it were a negative one, why, how, and where? Finally, determine if our architectural intervention could change that, and act accordingly. These interventions could group species together due to some cases of mutual needs, and for obvious reasons, create a biodiverse environment.

The 10 messages for 2010: urban ecosystems, by the European Environment Agency (EEA) argues that in order to master the challenge of urbanism, urban areas should be looked at as being opportunities and not obstacles for endorsing biodiversity. The framework would entail allowing greenery and biodiversity to spread into the urban fabric. (Edwards, B., 2010)

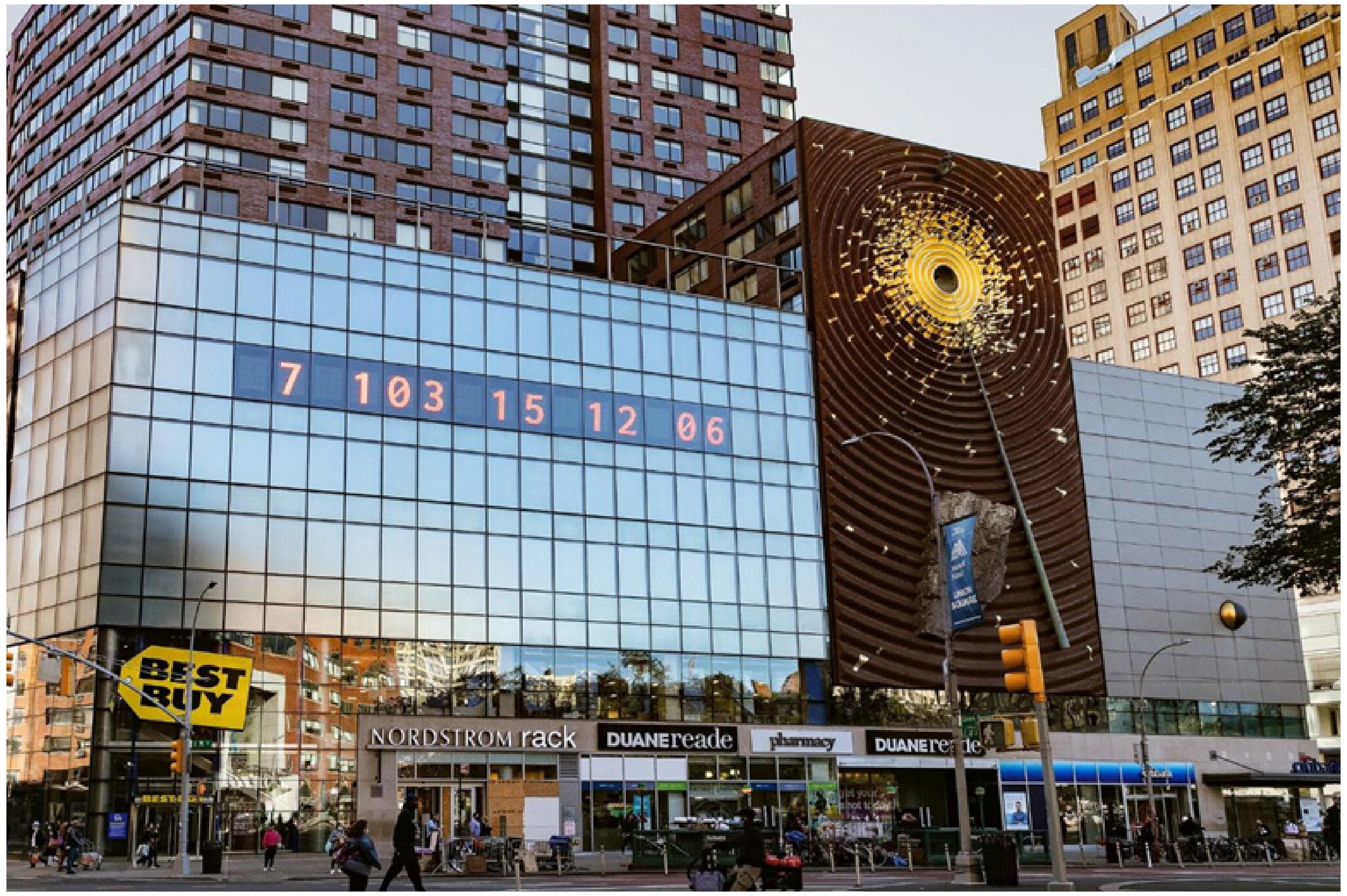


Figure 6: Metronome and its Climate Clock, soon after it was activated.
© Jeenah Moon.

Figure 7: : Interior rendered view of the House on Ile René-Levasseur.
© Mark Foster Gage Architects.

These biodiverse corridors would infiltrate through gardens, parks, urban wetlands, cemeteries, and roadside trees that can be linked into a network of planted roofs, balconies, and whole facades.

For instance, growing public awareness of the crisis in rural beekeeping caused by the collapse in bee numbers, is motivating Paris to become the centre of apiculture with rooftop beehives across the city. There are around 400 colonies of bees on the rooftops of Paris. Air pollution in cities is greater than rural areas, however, there are lower levels of pesticides allowing the urban bees to outperform their country cousins. Potentially, small thoughtful interventions like these can produce an ecological richness and provide the kind of biological robustness and beauty lacking in farmed landscapes. (Operadeparis, 2016)

(Figure 7) From the previous page, the site of the project in rural Quebec is a remote and undeveloped island in the center of Lake Manicouagan. The site is covered with old-growth taiga forest which makes the construction that has the ambition to remain pristine nearly impossible. Therefore, architect Mark Foster Gage sought to exaggerate the sites primordial botanical qualities. The large massing provides deep angular ledges and shaded nooks to encourage plant and moss growth. The primary cladding material itself is a very porous travertine, receiving accumulations. These rough surfaces provide further footholds for vines and plants. (Gage, M. F., 2015)

What would normally be an architectural nuisance: future plant growth, sediment, weathering, and staining from the surrounding forest are strategically planned into the lifespan of the project and work towards its aesthetic ambitions. Instead of becoming merely another glassy modernist home in a bucolic natural setting, the House on Ile René-Levasseur further explores philosophical concepts from Object-Oriented Ontology and Dark Ecology that suggest it is possible for an architectural project to withdraw from its mere building-ness and become something else, something discovered, mysterious and seemingly ancient and primordial in its relationship to its botanical context. (Gage, M. F., 2015).

However, the integration of nature in architecture isn't a straightforward task. Issues could present themselves, such as high maintenance costs, daylight obstruction in the case of living façades, thereby adding to energy use. These conflicts are created since nature is dynamic whilst architecture is static, hence zones and layers should be determined. For instance, a planted façade needs its own sub-frame ahead of the building vertical plain with integrated irrigation. A roof garden is also best conceived as another separate layer, mediating between the external and internal temperature. (Edwards, B., 2010)

(Figures 8 - 9) The building envelope functions as a self-sustained skin. The skin consists of a species of hydroponic ferns that are not local and require a certain kind of bacteria to grow. The bulbous glass beakers "blowing components" are used for the bacterial production. An individual drop by drop system aids in this process which is fueled by rainwater.

Therefore, the architects at R&SIe(n) have created their own natural conditions capable of accommodating a species of flora that would not have been able to grow in the Parisian conditions. The architects are effectively using synthetic systems and materials (bulbous glass beakers) to create a microclimate that aids the growth of ferns. The neighborhood is both attracted by the green aspect and repulsed by the brewage and the process to produce it.

Hence, a micro-biodiverse environment has been created in the heart of the dense city of Paris. The ferns introduced are a new species in this context and could be used as generators for new biodiverse possibilities. This man-made intervention can be defined as "Positive Anthropocene".

Figure 8: Private laboratory building envelope made by R&Sie(n). Hydroponics ferns and glass beakers acting as blowing components for bacterian production and collecting rain for watering plants.
© Archdaily.

Figure 9: Private laboratory building envelope made by R&Sie(n). Hydroponics ferns and glass beakers acting as blowing components for bacterian production and collecting rain for watering plants.
© Archdaily.

2.2.3 Materials

Materials experimentation into the novel and unconventional building materials that derive from this era will emanate a new vernacular architecture composed of synthetic materials found in the geological layers of the Anthropocene. Urging us to shift temporarily from 'materials of design' to 'design of materials'.

Materials should elicit meaningful user experiences in and beyond their utilitarian assessment. This requires qualifying the material not only for what it is, but also for what it does, what it expresses to us, what it elicits from us, and what it makes us do. (Karana, E. et al, 2015)

Although, it is more subtle, material usage can be an effective way to enlighten the users about our anthropogenic impact. Simultaneously, it shows that it can be reused in a creative and efficient way.

Reusing materials is by itself an act of ecological awareness. It just so happens that by using them and maintaining some of their old features apparent in buildings or urban fixtures, they become recognizable and therefore identified by users. Hence, it doubles in its effectiveness of being sustainable.

When composite reused materials, are thought with this notion of keeping its components old traces apparent, they gain an aesthetic value. Analogously to handmade crafts, each block or panel of this material would be unique, in its non-homogeneity it would distinguish itself from the mass produced blank homogeneous material products.

These composite materials communicate about their formation, the place that they came from and their circumstances. Users would be able to take notice of the origins of this material. It's important that at some level of inspection, the material communicates something to the viewer, it becomes a media at that point. Now a relation could be discussed about the material used as media.

Material scientists, artists and architects have worked together to experiment with ways to process and use these new synthetic materials.

(Figures 10 - 11) Combining decade-old masonry bricks with week-old plastic bricks, the "Plastiglomerate" bench explores material permanence and temporality within the fleeting context of Roskilde festival. The shifting heights of the bench invite a variety of activities and interactions, revealing the bricks in different ways depending on how they're touched, seen, sat on, stood on, etc. (Geiger, V., 2018)

The project was initiated and led by artist Veronika Geiger and her research into plastiglomerates - a new type of stone found in Hawaii in 2012 that is part organic and part plastic. By reconstructing the stone with organic material and plastic, in collaboration with Technical University of Denmark (DTU) students, Veronika explores new ways of creating landscapes. This aims to question how we relate to geological layers created by humankind, where timescales, materials and stories merge to create completely new narratives.

Can the plastiglomerate phenomenon be useful as a future building material? Through the project the aim is to raise awareness about the phenomenon and discuss the following: What does a balanced planet look like? Can we speak of equality in relation to the biological economy of the Earth? Does equality play a role in our thinking about environmental resources? How will the natural economic balance look like in the future?

These bricks used for building a bench reminds us of a ruin or crater. It is built with reclaimed bricks (112 years old bricks from a Copenhagen chimney, showing the marks of countless fires) and new fabricated bricks. The bench is both a construction to walk in/on and to sit on.

Figure 10: Plastiglomerate, a brick installation for Roskilde festival in Denmark.
© Benjamin Wells.

Figure 11: Plastiglomerate, brick process for Roskilde festival in Denmark.
© Veronika Geiger.

Construction waste is one of the world's largest waste streams. It accounts for around 30% of all waste in Europe. Construction & demolition wastes include concrete, steel, wood, asphalt shingles, and bricks. Demolition, results in millions of tons of concrete waste and large quantities of construction products rejected for non-compliance with the required specifications. Furthermore, most of the waste is generated during demolition, with only a small percentage at 10% to 30% generated during construction (EPA, 2018; Ning, 2017). The construction & demolition waste reduction, reuse, and recycling has become a critical and urgent issue. Improper treatment will result in serious environmental issues and land use hazards.

Countries across the world are reducing the construction & demolition waste by enacting new regulations and increasing public awareness. European countries amongst others are at the forefront in construction waste treatment and reuse. According to the European Union statistics office, the overall quantity of waste generated in the European Union was over 2.5 billion tons, with construction and demolition operations accounting for nearly 860 million tons (Bravo et al, 2015).

Recycled aggregate, which comes from building and demolition waste, can be used to replace natural aggregate partially or completely in concrete. This is one of the most efficient methods for repurposing the waste. However, there are some limits to using recycled aggregate in concrete, as outlined by European Standards. Even though many studies have shown that full replacement of natural gravel with recycled aggregate produces good results, these criteria only allow for partial replacement of coarse natural material with recycled aggregate. Furthermore, fine recycled aggregate from the waste has been used to replace natural sand in investigations. However, the fine fraction cannot be easily collected.

An experimental take on construction and demolition waste recycling was developed by T+E+A+M architects in the form of columns for the Designing Material Innovation Exhibition at the California College of the Arts. The waste is treated differently with a search for different aesthetic results with the aim to connote the appearance of the column as a medium for awareness of the waste created in the construction and demolition processes.

(Figures 12-15) Clastic Order is a series of free-standing columns made by combining reclaimed construction waste with post-industrial plastic waste. The columns are the first full-scale demonstration of T+E+A+M's ongoing research on the strategies and aesthetics of reassembly.

Reassembly brings together material fragments that have prior values, uses, and histories, into new architectural forms. As a strategy for material reuse at the scale of building.

The geological term clastic describes a type of stone made of older rock fragments, or clasts. Here, familiar fragments of buildings (brick, concrete, glass, pipes, and fittings) are the clasts which mottle the stone-like surface of the columns. Each column is monolithic, fabricated as a continuous cast with a process similar to slip-forming concrete, a technique used to cast uninterrupted structures such as building cores, shear walls, and silos. Each column cast begins on the ground in an insulated mold filled with loose material. The plastic is brought to its melting point at which time it binds the inorganic aggregates into a solid mass. The heat sources and formwork are gradually raised as each section is completed, producing continuous full-scale columns.

While the classical orders of architecture established mathematical rules of proportion, spacing, and sequence of parts, Clastic Order suggests an approach to design based on material behavior under heat and gravity. By varying the ratios of components in the mixture and the application of heat, a range of colors and textures is produced across the columns. Since the waste plastics and construction waste are reclaimed locally, the material properties of the resulting casts reflect regional waste streams. (T+E+A+M, n.d.)

Figure 12: Clastic Order column made from locally sourced wastes, produced for the Designing Material Innovation exhibition at the California College of the Arts.
© T+E+A+M.

Figure 13: Clastic Order column made from locally sourced wastes.
© T+E+A+M.

Figures 14-15: Clastic Order column made from locally sourced wastes.
© T+E+A+M.

3. Plastic Waste-Based Composite Building Materials

Figure 16: People's pavilion - The colored facade tiles made from plastic household waste materials collected by Eindhoven residents, made by architects Overtreders W, bureau SLA.
© Filip Dujardin.

3.1 Plastics Building Material Properties

Circular economy is quickly becoming one of the most important topics and a necessity following the recent EU directives. (European Commission, n.d.) The ability to recycle industrial wastes in the synthesis of new materials is undoubtedly one of the smartest ways to avoid waste while also giving it value. Composite materials are adaptable systems that allow waste to be recycled while also improving mechanical qualities.

Plastic disposal is a very apparent global issue. Plastic waste appears to be unavoidable from the highest peaks to the deepest ocean trenches. They are essentially indestructible under natural settings, yet they are thrown on a massive scale around the world: Over 359 million tonnes of plastics are produced each year. The environment cannot deal with their disposal quickly enough to avoid harm to living organisms. According to the United Nations Environment Programme (UNEP) only 9% of all plastic waste produced throughout history has been recycled. 12% has been incinerated, with the remaining 79% ending up in landfills, dumps, or the natural environment.

As a result, it has become widely accepted that plastics are unsustainable materials. While plastics are undoubtedly a significant issue, they do not have to be so. The problem isn't with plastic as a material; it's with the linear economic model, where items are made, consumed, and then discarded. This model implies unending economic expansion while ignoring the planet's finite resources. However, there are a variety of ways we might give plastics a circular life cycle, including turning discarded plastics into a resistant, dependable, and durable building material.

The properties of plastics as a building material varies between the types of plastics. Therefore, each plastic material should be assigned to a particular usage according to its particular properties. The success of plastic as an engineering material is determined by the type of plastic chosen for which use.

Plastics used in the building & construction field, come in a variety of shapes and sizes, including pipes, sheets, and films. They are moulded or expanded to make low-density materials. They are employed in paints, varnishes, and adhesives after being dissolved in solvents or spread as emulsions. Plastics are currently used in structures mostly in thin coatings, panels, sheets, foams, and pipes. They will help traditional construction materials perform more efficiently and affordably by extending their usefulness and life. (Anupoju, S., 2018)

Similar to any other building material, plastics present advantages and disadvantages. Hence, it is crucial to understand their properties. These variances are regulated for the products to be usable and accepted, plastic products are internationally standardized by the American Society for Testing and Materials (ATSM).

Temperature, moisture, UV radiation, thermal stress, chemical environment, mechanical stress, microbiological activity, and atmospheric pollution are all important factors to consider in plastics applications when it comes to long-term degradation. Depending on the kind of polymer and the presence of synergetic effects, these characteristics may or may not have an impact on the polymer structure, and subsequently their functionality.

- Appearance

Plastics can be produced in a multitude of shapes and colours. They provide a wide range of aesthetic properties, such as transparent, coloured. To achieve these diverse appearances, suitable pigments are added throughout the production process of the plastic.

- Chemical Resistance

Plastics in general are very resistant to chemicals and solvents. However, the degree of chemical resistance is determined by the organic chemistry law, which translates to chemical reactions tied to the types of molecular groups along a plastic's chains. The rate of chemical reactions is mainly controlled by the temperature. Most plastics on the market are very resistant to corrosion.

(Kay, D., Blond, E., Mlynarek, J., 2005)

- Dimensional Stability

The capacity of polymers to keep their size under varied environmental circumstances is referred to as dimensional stability. Consequently, a dimensionally stable plastic displays moderate thermal expansion and little water absorption.

Plastics only absorb a small amount of water. The amount of moisture absorbed is determined by the type of plastic used as well as environmental factors such as temperature, humidity, and contact time.

Polytetrafluoroethylene (PTFE) is the only polymer that does not absorb water. Amongst the plastics that present very low water absorption are Polyethylene Terephthalate (PET), Polyphenylene Ether (PPE), Polypropylene (PP), and Polyethylene (PE). (Ensinger Plastics, n.d.)

A high absorption of water causes dimensional changes in products, as well as a decrease in strength and electrical insulating properties. The coefficient of linear thermal expansion describes how much a material's length changes when its temperature increases or decreases. Plastics have a substantially higher factor of linear thermal expansion than metals due to their chemical nature.

Linear thermal expansion should be considered when dealing with tolerance-sensitive components, extreme temperature swings or composites containing metallic components.

- Ductility

The definition itself of ductility, being the degree to which a substance can be deformed plastically, illustrates how much plastic is ductile. Plastics, therefore, can fail under tensile load without warning. The fracture behaviour of plastics is driven by microscopic mechanisms functioning in a heterogeneous zone near their crack or stress tip.

- Durability

Durability is described as the ability to remain unchanged for an extended period.

The molecular structure of the material is the first attribute to consider, because plastics age primarily at that level, or in relation to additives or other components used in the manufacture of the material.

Each molecular group along the polymer chain has its own stability because the polymer is made up of monomers. The material's cohesiveness is also controlled by the chemical makeup of the polymer chain. As a result, the chemical makeup of polymer chains will dictate the types of physical and chemical degradation mechanisms that are likely to occur in the material.

As Kay, D., Blond, E., Mlynarek, J., (2005) state, the product's structure can be altered by the following characteristics.

- Linearity, cross-linking and branching level of the chain structure of the polymer.
- Length of polymer chains distributed in the material affect its weight balance.
- Morphology consisting of the relative orientation of the polymer chains, and their crystallinity,
- Inconsistencies due to impurities or irregularities in the structure.
- Additives used for many purposes such as: antioxidants, UV stabilizers, plasticizers, etc.

There are two types of degradation mechanisms one is manifested physically and the other one chemically.

Degradations that do not entail a change in the molecular structure of polymer chains are referred to as physical aging.

- Additive extraction: Antioxidants, UV stabilizers, pigments, plasticizers, fillers, and other additives added in some plastic materials play a crucial role in the material's long-term performance. Some exposure conditions can cause the additives to be partially or completely extracted from the substance.

- Solvent action: Weak inter-chain interactions connect polymer chains. This presents an issue for polymer chains' cohesiveness, the interaction between the chains must be stronger than the contact between the solvent and the polymer.

Most polymer-solvent interactions are based on electric polarity. The higher the polarity of the solvent and the polymer, the stronger the interactions between them are. That explains why low-polarity polymers like polyethylene and polypropylene are chemically resistant to most chemicals.

- Internal chain reorganization: It can be thermally induced or stress-induced also known as creep or relaxation.

Morphological changes in the material, which might impact its qualities (dimensions, mechanical resistance, etc.) can be caused by heat exposure. In fact, heat increases chain mobility, which can encourage internal chain reconfiguration in the presence of internal stress.

- Thermal stress: Apart from some chain reorganization processes such as chain relaxation, a temperature increase causes the material to dilate, while a temperature reduction causes it to contract. Thermal stresses are created when material deformation is limited.

When the temperature rises or falls, thermal dilation or contraction causes a change in the overall dimension of the plastic product, causing wrinkles when the temperature rises and tension when the temperature falls. This issue is addressed at the building stage by welding the said product at low temperatures, approaching if possible, to the service temperature that the material will support over its service life.

Chemical aging is defined as a process in which the chemical structure of polymer chains changes.

- Thermal degradation: it is caused by the energy provided by heat, and it entails changes in molecular bonds along polymer chains.

Thermo-oxidation of polymer chains occurs when thermal degradation is made in the presence of oxygen. By lowering the temperature, oxygen sensitizes the substance, allowing for the initiation of deterioration.

Antioxidants and other stabilizers are put into the resin to extend the induction period. To test antioxidant efficacy and determine the level of oxidation protection of materials, a variety of approaches can be applied. Accelerated aging tests like Oxidation Induction Time (OIT) and Long-Term Heat Aging (LTHA) can be used to assess antioxidant efficiency. In the specification of plastic materials, standard test procedures for the high pressure-oxidation induction time (ASTM D5885) and oxidative induction time (ASTM D3895) are frequently utilized.

- Photo degradation: It is a similar mechanism to thermal degradation. However, instead of heat, radiation is used to provide energy. The ozone layer and the atmosphere operate as a filter, intercepting sunrays with wavelengths less than 295 nm. The sunray wavelengths that do get it through, however, are the most harmful.

The rate of photo-oxidation degradation of polymers is influenced by several factors. The most important ones are irradiance and oxygen permeability, although other elements such as temperature and moisture also influence the rate of degradation.

The solar spectral distribution is affected by the sun's location in relation to the horizon. As a result, it varies depending on the location on Earth, the season and time of day, air pollution, the surface orientation, the presence of surrounding shielding agents like vegetation, snow, dust accumulation, and opposite the presence of surrounding reflective agents like snow, water, etc.

UV stabilizers can be applied to plastic products to increase the induction period and lessen the sensitivity of polymers to photo-oxidation. Pigments, UV absorbers, quenchers, free radical deactivators , and hindered amine light stabilizers (HALS). UV absorbers and pigments operate as a screen, absorbing UV light before it causes harm. Quenchers deactivate excited states by eliminating energy from photon-excited liaisons and preventing the production of free radicals in the process.

Many other factors influence the pace of photo-oxidation-induced polymer breakdown. One of the most important factors is oxygen permeability, although other elements such as temperature and moisture also influence the pace of degradation.

However, given that a particular percentage of antioxidants is included in the formulation of a polymer, the thicker a material is, the longer it takes for oxygen to diffuse through it, and the stronger its resistance to photo degradation.

- Chemical resistance: as already mentioned about the physical impact of solvents on polymer materials, chemical substances that encounter the plastics can also change the structure of the polymer chains.

Chemical reactions with polymers are governed by organic chemistry laws. The sorts of molecular groups along a polymer's chains are closely tied to its amount of reactivity to a given chemical.

- Hydrolysis: This is a common sort of chemical degradation process that involves water and certain polymers, such as polyester.

Imides, amides, urethanes, ethers, and esters are the most common chemical liaisons that are prone to be hydrolysed by water. The hydrolysis process in plastic materials primarily affects polyester plasticizers in flexible Polyvinyl chloride (PVC) and polyester fibres (PET).

The molecular structure of the material, such as the proportion of crystallinity, has an impact on hydrolysis. A high proportion of crystallinity slows the rate of water diffusion in a neutral or acid environment, slowing the pace of deterioration. A high amount of crystallinity slows the rate of surface erosion in an alkaline environment.

- Electric Insulation

Due to their high resistivity, most plastics are excellent insulators of electricity. Plastics have low-energy valence electrons in the outer atomic band and no 'free' electrons like metals. As a result, they will not enable current to flow through them from another source. Hence, their usage for electronic tools.

- Finishing

The finishing of plastic products depends on the mode of production. Plastics can be given any form of finishing treatment. Having technical control during manufacturing allows for mass production of plastic products with uniform surface finishes.

- Fire Resistance

Generally, plastics are carbon-based materials therefore, they will burn, produce smoke, and emit fumes when exposed to fire. At extremely high temperatures, they will disintegrate into volatile and gaseous combustion products.
The type of plastic has an impact on how it reacts in the combustion process. At high temperatures, thermoplastics soften, typically before ignition, thermosetting materials react differently, they do not soften but rather experience localized surface charring with occasional flaming, and the charred residue when kept in place creates an insulating layer.

Fire resistance can be tested in laboratories for quality control. Tests evaluate the burning behaviour, the gases and smokes. However. these tests cannot predict real fire scenarios, due to the varying performance of plastic products. Various factors come into play such as: fibre content, the degree of cured resin, the flammability of the fibre reinforcement, and flame retardants or additives.

The burning behaviour can be tested using the Limiting Oxygen Index (LOI) tool. It consists of measuring the percentage of oxygen needed to support the combustion of the plastic. Low flammability corresponds to a high LOI.

A candle-like sample is supported in a vertical glass column during the LOI test, and a steady stream of oxygen/nitrogen mix is introduced into the glass column. A flame is used to ignite the sample, which then progressively burns the unheated material. The oxygen/nitrogen ratio can be changed, and the test records the lowest oxygen concentration (in percentage) required to maintain combustion. However, inconveniently, this method does not illustrate the burning reaction of the tested plastic in an open atmosphere.

In order to examine an ignited flame, spread on a plastic product, Underwriters Laboratory (UL94) test tool has been developed. It is incorporated in the national & international standards (ISO 9772 and 9773). The UL classification scheme ranks highest the materials that burn slowly or self-extinguish and do not spill burned materials. The test entails burning a product for a particular time, and then investigate the products reaction after removing the flame source.

Toxic gases emitted during burning of plastics depends on the type of plastic, additives used, and lastly the particularity of the fire source, hence there are no current standards to regulate the plastic products for this aspect.

However, there exists a smoke quantifying technique called the Smoke Box test. This test quantifies the amount of smoke created per unit area, when a material is subjected to both radiant heat sources and burning.

To reduce the ignition or burning behaviour of most ordinary plastics, flame retardants can be applied. However, the usage of flame retardants has the disadvantage of increasing the amount of smoke produced during combustion.

- Fixing

Plastics can be drilled, bolted, or glued.

- Humidity

Water absorption is a natural property of several polymers. Moisture/water absorption refers to a plastic's or polymer's ability to absorb moisture from its surroundings. It has been proven to behave as a plasticizer, lowering the glass transition temperature and plastic strength however these effects can be reversed. Water absorbed into the polymer structure, on the other hand, might cause permanent degradation.

Among the consequences of water absorption on plastics can be identified, changes in dimension and mass of the material, possible extraction of water-soluble components. These lead to non-negligible mechanical and electrical performance changes (tensile strength, elasticity, and impact strength).

Water absorption is tested by water immersion of the material in question for 24 hours at a 23ºC, at 100ºC. The measurement occurs when the materials stop absorbing water. A third test can be made specific to determining the plastic's humidity resistance, when the material is put in conditions of air with 50% relative humidity at the specified temperature of 23ºC for 24 hours. The results shown are means to compare the initial weight of the plastic to the plastic after being tested.

- Maintenance

Unlike other materials, plastics are very easy to maintain. They don't require any surface finishing coatings, paints, or other similar applications.

- Melting Point

Plastics have a general range of 20 to 120ºC molding temperature, and a melting temperature ranging roughly around 200ºC to 300ºC. Rendering them, a weak material in relation to heat. Therefore, high temperature contexts should be avoided for plastic products. Thermosetting plastics break down at higher temperatures than that of thermoplastic plastics. Their break down lead to permanent changes upon cooling, therefore, glass fibre reinforcement could be used to improve heat resistance.

- Recycling

It's crucial to understand that plastics can be classified into two categories:

- Thermoplastics: made of rigid materials, go through a melting and cooling process. This sort of plastic is simple to recycle because it only requires remelting and reshaping the plastic in order to be repurposed.

Although, recycling them, has its limitations due to the characteristics changing with each processing cycle. Thermosets are formed by crosslinking processes. Because of the heating process that causes chemical degradation, these polymers are more difficult to recycle.

- Sound Absorption

In terms of sound absorption, recycled porous materials achieve comparable values to natural materials (Desarnaulds et al., 2005). Sound absorption properties vary depending on the porous characteristics of the plastic, narrower pore channels lead to a smaller permeability for acoustic waves.

Sound insulation also depends on the binding application, paying attention to the downward accumulation of the binder, in order to not heterogeneously bind the plastic and simultaneously affect the sound absorption.

- Flexural Strength

The flexural strength of plastic is standardized by ASTM D790. The ability of a material to resist deformation under load is characterized as its flexural strength. The load at yield, commonly measured at 5% deformation/ strain of the outer surface, is described as flexural strength or flexural yield strength for materials that deform appreciably but do not break. The concave surface of the test beam is under compressive stress, while the convex surface is under tensile stress. Flexible materials, such as elastomers, have lower values than fibre reinforced technical polymers, such as polyimides or acetals, which are utilized as metal alternatives.

Reinforcing plastic with fibrous materials improves the flexural strength of the composite plastic material.

- Thermal Property

Plastics are good heat insulators because they have almost no free electrons to conduct heat. The thermal conductivity of plastics is often tested using a guarded hot-plate setup according to ASTM C177 and ISO 8302. Between two plates, a solid sample of material is inserted. One plate is heated, while the other is chilled or only slightly heated.

Thermal conduction is transferred by means of gas molecules found in the porosity, and the oscillation of atoms within the crystals found in plastics, known as phonons. Thermal conductivity is reduced as the interbond path length is reduced, resulting in increased thermal insulation. Contrarily, the crystallinity in polymers increases the thermal conductivity due to a higher density.

- Weight

Plastics are light in weight and easily transportable in big quantities. They have a low specific gravity, which typically ranges between 1.3 and 1.4. The density of an object is divided by the density of water to determine its specific gravity. Water has a density of 1,000 kg per m³. (Kay, D. et al 2005)

- Particulate Matter Resistance

The effect particulate matter has is the acceleration of the "natural" corrosion of materials. When a building is exposed to the outside environment, it undergoes physical changes and chemical interactions. With the presence of water (or moisture) and oxidizing agents, gaseous pollutants such as sulphur dioxide and nitrogen oxides can react immediately. Resulting in physical damage or loss of material when washed away.

Today, particulate matter is still a recent topic of study, not enough research has been made about the long-term effects it has on plastic. Some research has been done on different building materials in a study examining 3 years of exposure in a highly polluted atmosphere such as Cairo, Egypt.

The materials investigated such as limestone, sand-lime, cement, plaster, and clay are the ones found in the historical buildings. This priority comes following the obvious reason of trying to understand how to better preserve our heritage of the built environment.

Chemicals react differently to each material, clear indications have revealed that mechanical properties are altered, and the compressive strength decreases with exposure to air pollutants. This is mostly due to exterior affects and internal weakness in materials caused by air pollutants' activity, as well as the alteration on the outer surfaces. (Mohammed, A.M.F., et al (2021)

The following case studies are examples of plastic waste-based composite materials used in architecture. The cases will be organized by the different elements that constitute a building (facade, roof, wall, and structure). In each case, the composite material and a project application will be studied. A look into the impact recyled plastic has on the composite materials' properties, and the reason for their considerations.

3.2 Structural Polymer Concrete

Considerations: The considerations made by Thorneycroft, et al (2018) are alternative solutions of the over-dredging of sand which have resulted in sand extraction limitations across India in particular, with obvious economic consequences for concrete construction. Hence, to meet the growing demand from the concrete construction sector, a viable environmentally acceptable substitute to sand must be identified. Simultaneously, plastic waste is rarely recycled in India's context, they amount to 40% of waste discarded in landfills. Dumping such materials, which decompose at a slow rate, is a long-term environmental hazard. The findings demonstrate that substituting 10% of sand by volume with recycled plastic is a viable option that could save 820 million tonnes of sand annually. The structural performance of concrete with plastic waste can be maintained with proper design. The goal was to make a structural concrete to investigate if plastic could have a wider application than non-structural concretes.

Materials: Five types of plastic were used as sand replacement. (PET, Paint Protection Film (PPF), High Density Poly Ethylene (HDPE), High Density Polypropylene (HDPP), Polyphenylene Sulfide (PPS)). Ten mixes of concrete with different plastic fragments sizes, including five different plastic types, and two cases of treated PET with sodium hydroxide and sodium hypochlorite.

Method: Experimental tests were conducted on ten innovative concrete mixes to discover potential candidate materials to be utilized as sand replacements, with the type of plastic being the only experimental variable. In all but one of the mixes, a constant replacement ratio of 10% by volume was employed, based on the previous results conducted in (Table 1) and the need to replace a sufficient volume of sand with plastic to see a change while minimizing potential strength losses. A reference concrete mix was prepared with a goal mean strength of 53 MPa, after 14 days. All preparation, mixing, and casting were done in compliance with the British Standard EN12390-2:2009. (Thorneycroft, J. et al 2018)

Properties

Compressive & Tensile Strength: Inadequate bond between the plastic and the surrounding matrix, is commonly observed when adding plastic to a concrete mix. This reduces compressive and tensile strength. Consequently, the most effective plastic aggregate for use in concrete should have a rough surface, be irregular in shape, and small enough not to cause substantial failure surface and minimize porosity. The compared types of plastics in the paper with the same replacement rate of 10%, vary in their performance in compressive strength from the weakest: PPF, HDPE, HDPP, PPS, PET. However, it has to be noted that a change in the replacement rate could alter the perfomances, moreover, depending on the use intended of the material, the tensile strength also has to be considered.

The most promising overall performance was achieved by using a graded PET plastic that had the size of the sand particles it replaced, and at a replacement rate of 10% by volume. With 54.4 N/mm^2 of compressive strength and 4.07 N/mm^2 of tensile strength, this combination was outperforming the reference concrete with not substitution at 53.8 N/mm^2 and 3.26 N/mm^2 respectively. (Thorneycroft, J. et al 2018)

Workability and Water Absorption: Due to the zero water absorption of plastic aggregates, the integration of polymer in concrete greatly improves workability (16.4% to 141% for 10% to 50% replacement ratios). Furthermore, the replacement with plastics reduces the fresh and dry density of concrete composites by a maximum of 13.6% and 18.2%, respectively. (Ahmad, F. et al, 2021)

Chemical Resistance: For the maximum replacement of Plastic a significant drop in sorptivity value (41.7%) can be seen. This means that the concrete will be more resistant to chemical penetration. (Ahmad, F. et al, 2021)

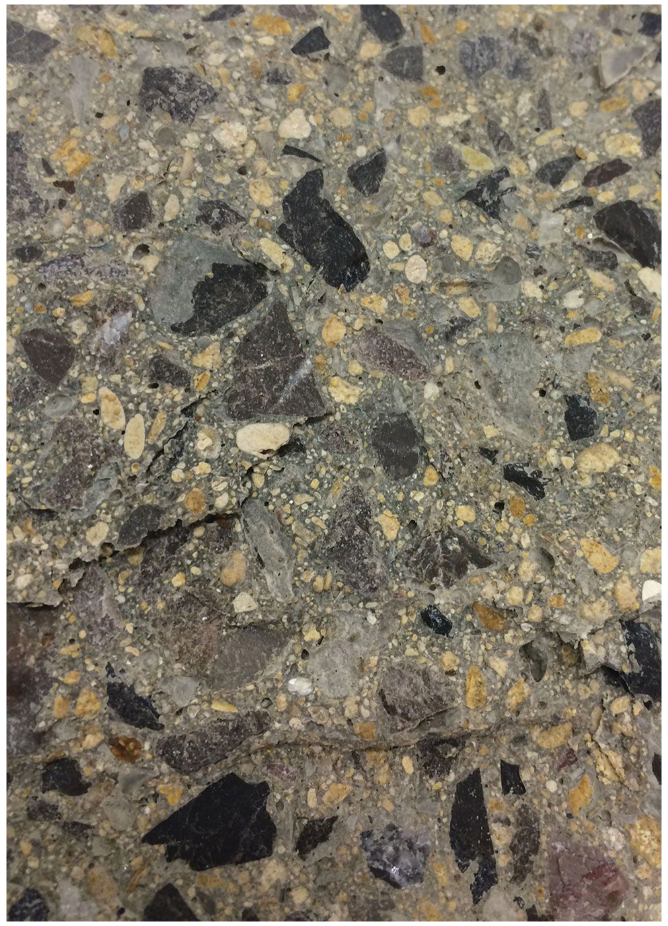


Figure 17: Close-up view of concrete with plastic particles replacing some of the sand.
© University of Bath.

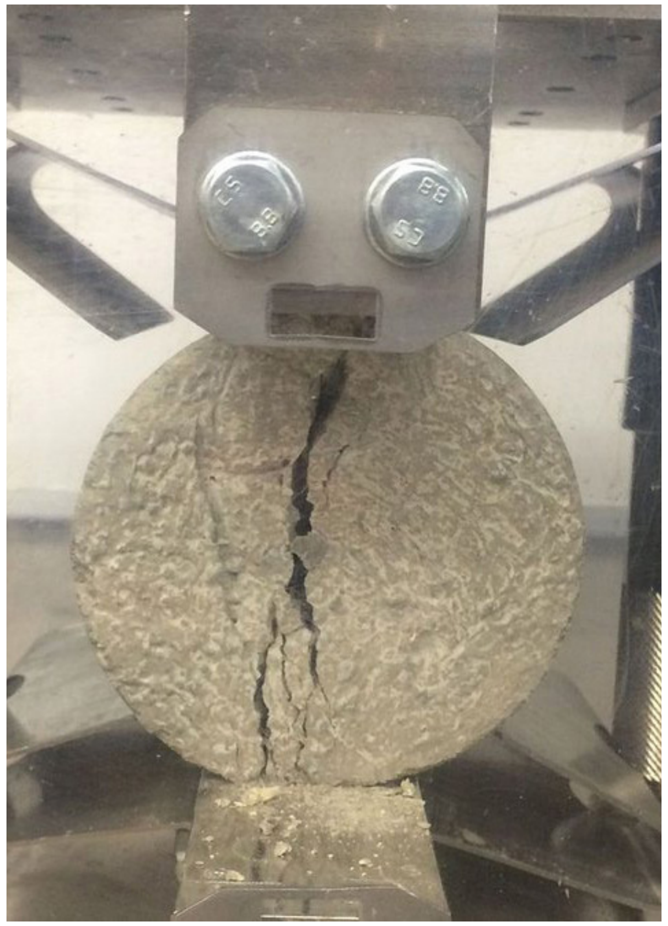
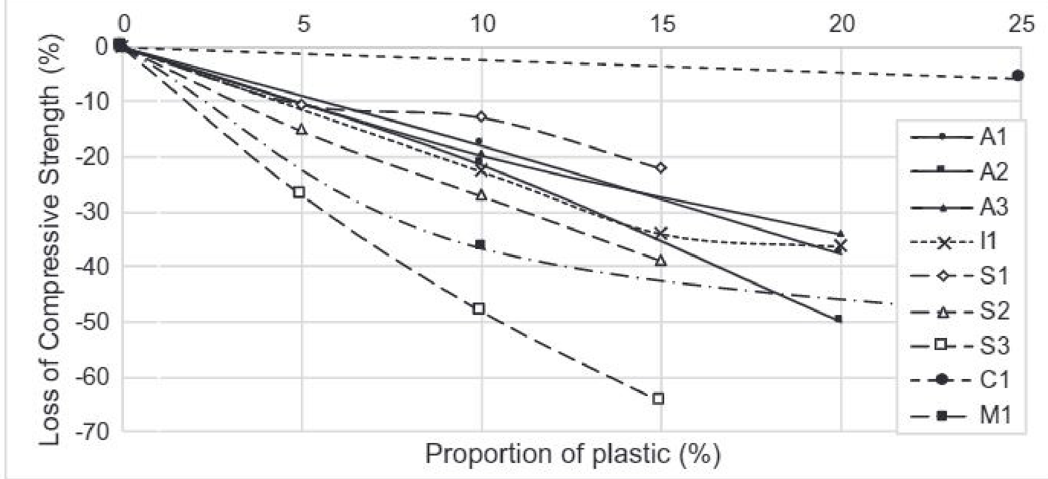


Figure 18: Compressive strength test on the cylinder sample.
© University of Bath.



	A = Albano et al. (2009)	I = Ismail and Al-Hashmi (2008)	S = Saikia and de Brito (2014)	C = Choi et al. (2005)	M = Al-Manaseer and Dalal (1997)
1	All small particles	PET and polystyrene	PP — cylindrical pellets	PET coated in GBFS	Angular particles
2	All large particles	N/A	PF — flaky fine particles	N/A	N/A
3	50/50 mix of particles	N/A	PC — large coarse particles	N/A	N/A

Table 1: The relationship between plastic replacement and loss in compressive strength. The different versions indicate the tests made with changes in w/c ratio, size, type, shape, surface texture and treatment from different previous studies.
© Thorneycroft, et al (2018).

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Cost Effective

Reduce Plastic Waste

Reduce Sand Extraction

Possible higher Compressive & Tensile Strength

Workability

Decrease Fresh and Dry Density

Reduce Sorptivity

Higher Durability

Improve Abrasion Resistance

Chemical Resistance

−

High Variability in Compressive Strength Test Results

Density

High Variability in Tensile Strength Test Results

Unknown Polymer Concrete to Steel Bond Properties

Figure 19: Recycled plastic bricks.
© Conceptos Plásticos. (2017)

3.3 Plastic Waste Roof Tile

Considerations: The cost of construction materials, as well as the natural resources required to manufacture them is growing at an unprecedented rate. Plastic waste is a major environmental concern due to its extensive usage, non-biodegradability. Therefore, reusing it instead of concrete into tiles would be significant. Moreover, recycling plastics is currently hard to manage due to the labor and capital-intensive process.

The proposed material would not only lower construction costs, but it would also work as a waste diversion, minimizing the environmental impact of plastic waste disposal. Furthermore, plastic can be combined with other recycled materials to produce alternative composite materials. This composite material uses fly ash which is produced as a result of pulverizing coal in power plants.

Materials: The materials are sourced locally, instead of using clay as for the traditional tiles, this product uses recycled PET, it is melted and then mixed with fly ash and river sand. The Shredded plastic bottle waste made of PET were obtained from a waste Resource Management firm in Bukit Mertajam, Malaysia. The fly ash was provided by a palm oil processing company in Penang, Malaysia. The river sand used in the project was provided by the School of Housing Building and Planning Resource Laboratory. The river sand used is considered to be a fine aggregate according to Standard. Its density of 2.38 g/m³ is at intervals of 2 - 2.4 g/m³ of natural sand.

Method: The shredded PET wastes are heated to 230°C in the aluminum pot before adding the Fly ash and fine river sand to the melted plastic wastes as shown in (Figure 21). The liquid mix was homogenized and put into an iron mold greased with engine oil for easy removal; the mold's edge was repeatedly pounded for several minutes to ensure correct cohesion. After one hour, the samples were demolded, cooled, and cured at room temperature for 48 hours before being tested.

Taken from: Taiwo. O et al (2021)

Properties

Porosity: The porosity of the tiles decreased with the increase of PET used. The results show at 30% of PET: 2.83% porosity of the tile and at 90% of PET 0.11% porosity of the tile. According to the norms related, the limit of acceptance is set at 2%. Therefore, with the combination used of river sand, fly ash and PET plastic, more than 30% of PET should be used in order to be verified.

Density: The density of the composite was decreased as the PET material was increased. The manufactured composite tiles with 100% PET possessed the lowest density (1070.2 kg/m³), while those produced with 30% PET content had the highest density (1764.7 kg/m³).

Compressive Strength: Increasing the PET waste content decreases the composite's compressive strength. The PET composites with the highest compressive values were those with 30% PET (11.07 MPa). However, it is important to note that this value is greater than the compressive strength of other common tiles. The compressive strength values increase steadily with increasing sand and fly ash content but decrease with increasing PET content.

Flammability: The results of the experiment revealed that the addition of river sand and fly ash aggregates to PET paste formed a barrier, causing the composite tiles to burn slower at 7.96 mm/min than the pure 100% PET plastic tile which has a linear burning rate of 21.21 mm/min.

Chemical Resistance: Comparative findings revealed no significant changes in sample weights or measurements after 7 days of soaking in different chemicals.

Water Absorption: The tested river sand used presented a low water absorption of 0.07%. Moreover, the PET used is for containing water bottles.

Figure 20: Eco slate plastic roof tile.
© Roofing Megastore.

Fly ash.

PET flakes.

River sand.

Figure 21: Melted PET flakes mixed with Fly ash, and river sand.
© Taiwo. O et al.

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Lighter Material

Easier, Quicker Installation

Lower Carbon Footprint

Higher Compressive Strength

Aesthetically Appealing Roof

Durable

Close to no Water Absorption

Upcycle

−

Non - Recyclable

No Information about Photodegradation

Figure 22: Eco slate plastic roof tiles.
© Eco Systems Distribution Ltd.

4. Turin's Plastic Waste Stream in Italy's Recycling System

Figure 23: Stacks of plastics to be recycled.
© Bruno Marion.

4.1 Italy: Plastic Waste Stream as to Europe's Plastic Demand

All plastic-containing materials that can be used to store, protect, handle, deliver, and present other products, are referred to as "plastic packaging."

The graphs (Figures 24 - 25) show an interesting correlation between plastic waste treatment - plastic packaging waste treatment and the Italian law established by the Consorzio nazionale Imballaggi (CONAI) (2015). Usually, chemical recycling, regulates materials and not products, however in Italy we talk about a regulation that recycles packaging therefore products and not materials. This explains the difference in the graphs showing the efficacy of recycling packaging however the plastic waste treatment in general in Italy falls behind with a higher percentage of landfilling than recycling or recovering energy. This is due to Italy missing to identify and treat a large part of the plastics waste that originate from various other industries that use plastics such as Building & Construction, Automotive, Electrical & Electronic, Household, Leisure & Sports, Agriculture, and others.

(Figure 26) Shows the plastics usage/ demand by industry in the European Union in 2019, it helps recognize the presence of the variety of industries sourcing plastics and it helps identify that indeed in Italy, by only recycling plastic packaging, a larger percentage of the plastic waste is going to landfills as of 2018.

As we have seen, (Figure 27) a change must be made in the Italian recycling system, starting by regulating the collection of all plastics based on material types and not only plastic packaging. Consequently, the recyclable plastics will be easier to separate between plastic and non-plastic materials improving the citizens contribution and the plants' sorting. Moreover, innovation is needed in the plastic material at the initial stage of production (pre-recycling) to make them more recyclable and at the stage of treatment (post-recycling) by uncovering ways to re-use difficult-to-recycle plastic materials and existent un-recycled ones. (Mariotti, N., Ascione, G.S., Cottafava, D., Cuomo, F., 2019)

Plastic recycling is an energy consuming operation; hence the golden rule is to always try to limit the waste to solve the waste accumulation, therefore preventing the plastic recycling processes that are produced either mechanically or chemically. Furthermore, Europe imposes a plastic recycling rate which in 2025 will have to reach 50%. (European Court of Auditors, 2020) It is therefore increasingly necessary to invest in research & development, to encourage recycling the fractions that are in the plastic packaging system of today in Italy not offering a valid or sufficient motive to recycle.

Due to the thesis subject being a hypothetical case study of a plastic waste-based building material applied in Turin, it is necessary to investigate and to understand in detail how Italy's plastic recycling stream functions. With that application in mind for building usage; the plastic waste we would like to examine is the one being sorted by the Consorzio Nazionale per la raccolata, il riciclo e il recupero degli imballaggi in plastica (COREPLA). The study's focus on plastic packaging came as a result, after having contacted the waste collecting municipal company in Turin, Irene, who has directed me to contact COREPLA. Thanks to a videocall meeting with an engineer at COREPLA, (Eng. Davide Pollon) a conclusion was attained about which plastics coming out of which field should the study be looking for.

Plastics used for packaging is the most suitable due to them being used for domestic purposes. Therefore, eliminating the risk of toxicity that could have been an issue with plastics sourced from the automotive industry for example. Furthermore, Italy's context specifically helps our study due to its elaborate system revolved around recycling plastic packaging. Hence, an informed decision can be achieved.

In fact as seen in the graphs, plastic packaging in Europe presents the highest percentage of demand compared to other segments such as Building & Construction, Agriculture, Automotive, Electrical & Electronic, etc.

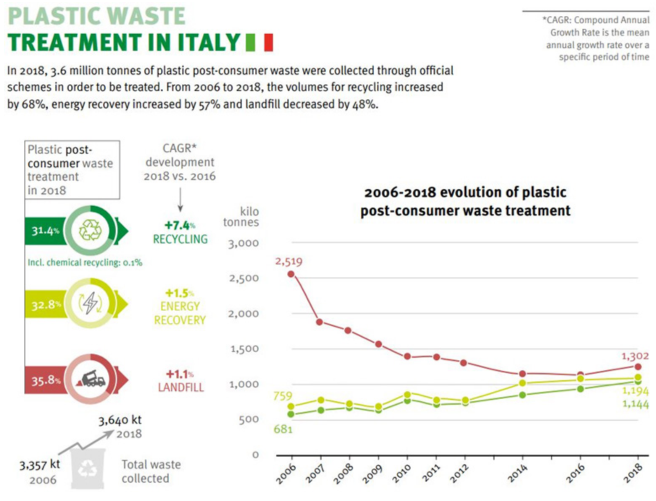

Figure 24: Plastic waste treatment in Italy.
© PlasticsEurope.

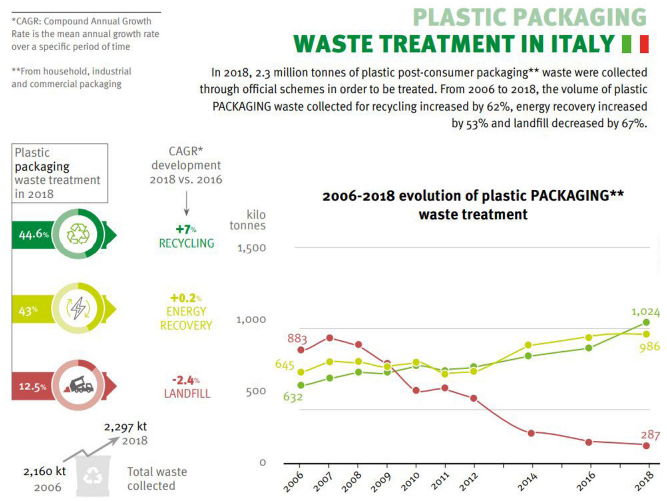

Figure 25: Plastic packaging waste treatment in Italy.
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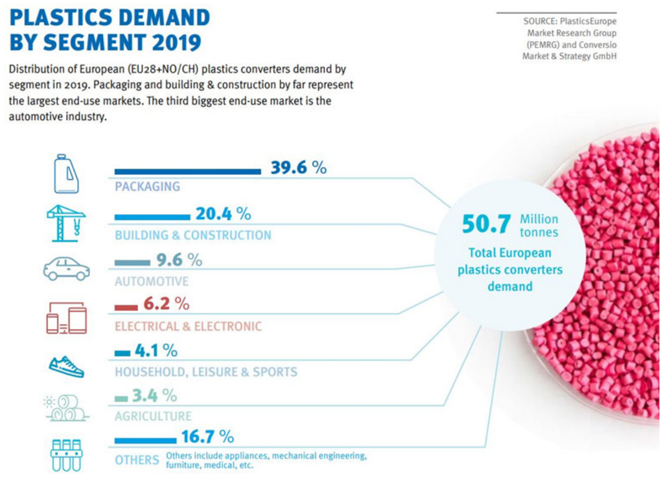


Figure 26: Stacks of plastics to be recycled.
© PlasticsEurope.

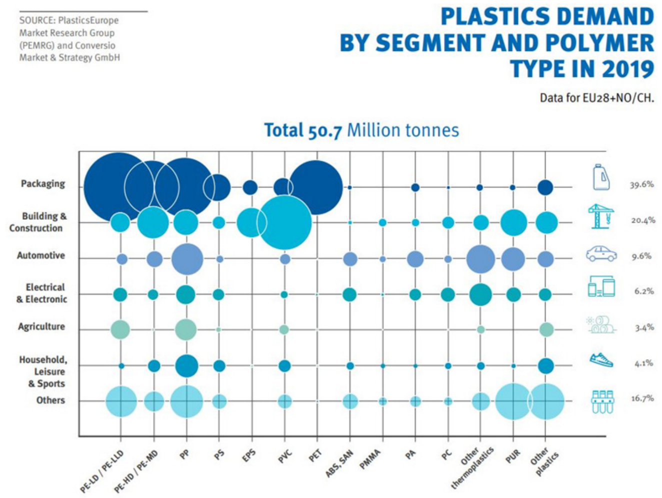


Figure 27: Stacks of plastics to be recycled.
© PlasticsEurope.

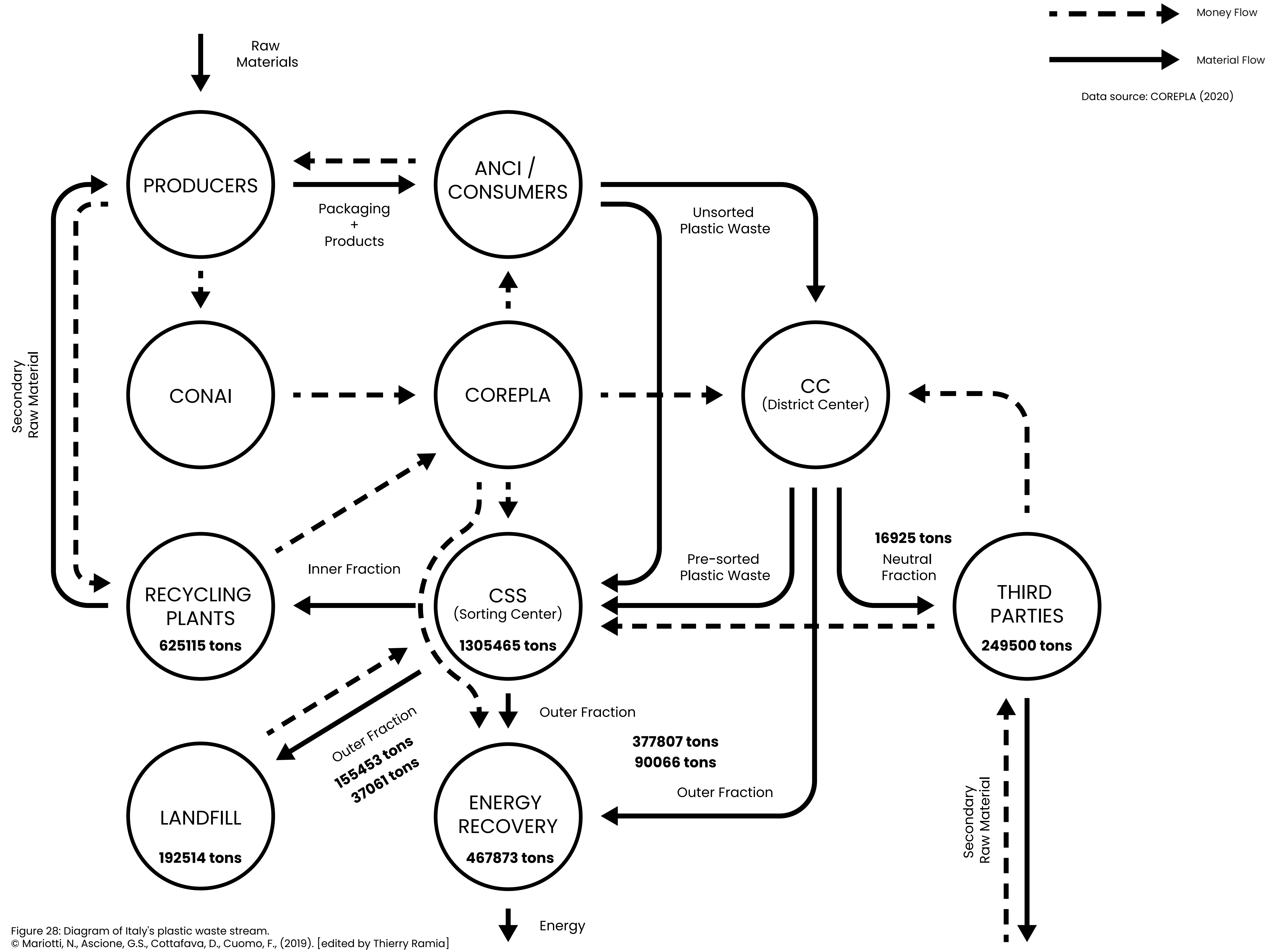


Figure 28: Diagram of Italy's plastic waste stream.
© Mariotti, N., Ascione, G.S., Cottafava, D., Cuomo, F., (2019). [edited by Thierry Ramia]

The Italian plastic packaging supply chain is regulated, at a national level, by a unique actor, COREPLA. It is the national consortium intended for collecting, recycling, and recovering plastic packaging. The Italian plastic packaging ecosystem is composed of several private and public stakeholders as shown in the diagram above.

The plastic packaging supply chain in Italy starts with getting raw materials to produce plastic packaging products, this is made by industries specialized in producing plastic packaging, the production depends on the demand of the consumers.

These consumers use these products for a varied period of time and then disposes of them in the trash. Optimally, the consumer practices good recycling behaviour and the municipal trash offers separated trash.

The plastic waste is then collected by a public or private multi-utility service company and brings it to a district center owned by a third-party company or by the municipality/ multiutility itself.

The plastic waste is then sorted and cleaned in the sorting centers which are owned by COREPLA's subcontractors. The plastic packaging waste is then divided into an inner fraction (recyclable), an outer fraction (waste that is heterogeneous and comprises of glass, paper, and non-packaging plastics) and finally a neutral fraction (plastics not recognized by CONAI-COREPLA).

In Italy, there are 966 District Centers (CC) and 33 Sorting Centers (CSS), they can be found across the national territory according to territorial proximity to reduce transportation distances and costs. (COREPLA, 2020)

The charts on the right are an analysis of the data publically published by COREPLA on their official website.

The first chart shows the means and percentage of plastic packaging waste treatment in Italy. Compared to 2018's data shown in (Figure 25) a decrease of 7.6% in landfilling can be noticed from 12.5% to 4.9%, showing a good sign of improvement.

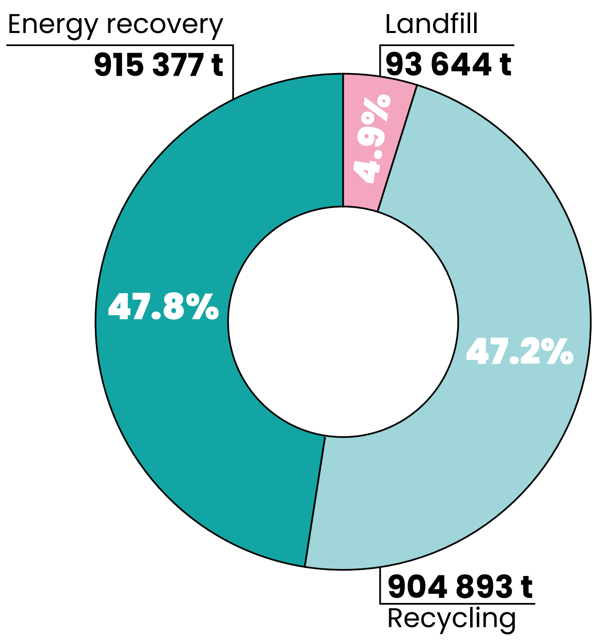
However, this improvement for the most part comes from an increase of energy recovery. From 43% in 2018 to 47.8% in 2020, an increase of 4.8% in energy recovery surpasses the lesser improvements made in recycling, passing from 44.6% to 47.2% amounting to an increase of 2.6%. (COREPLA, 2020)

This analysis shows that a transition is happening in Italy, relying more on energy recovery than recycling. The product based (non-material based) waste treatment system dependent on plastic packaging is hindering any improvement of recycling due to large reforms that would have to happen for it to see the light. A material-based system would entail switching the finances from companies that produce the plastic packaging products to the companies that produce the plastic. (Mariotti, N., Ascione, G.S., Cottafava, D., Cuomo, F., 2019)

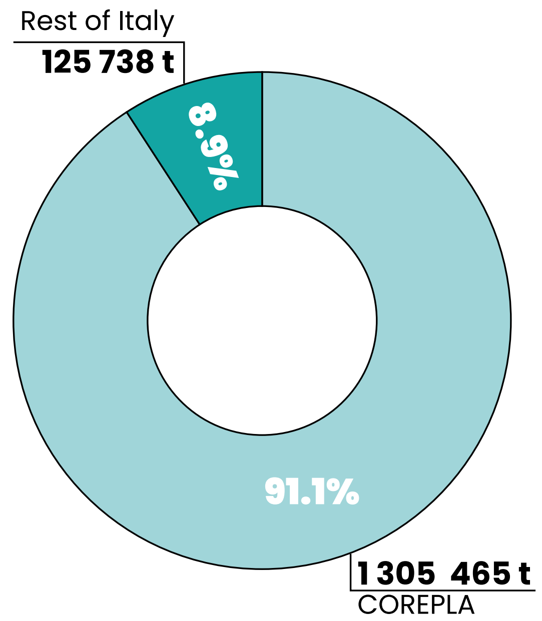
The two following charts compare the waste sorting between COREPLA and the rest of Italy's plastic waste treatment companies. This data is important for our subject matter in order to give us an idea of the quantity being disregarded.

The remaining 120275 (t) of plastic packaging being sorted by the other companies are not to be neglected, moreover they show an even bigger potential in the variety of sourcing available in Italy's context. However, due to the large variety of companies, and for the purpose of showing the big potentiality of the study at hand, it would be appropriate to only use COREPLA as our provider.

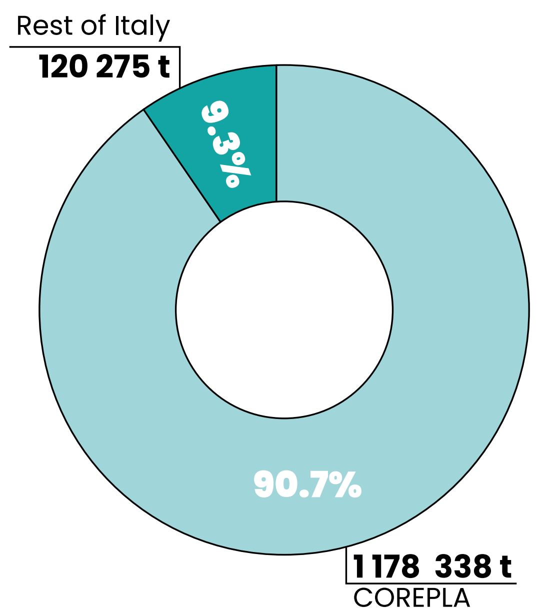
This means that onwards, we would be looking at the 1178338 (t) of plastic packaging waste being sorted by COREPLA at the national scale. The percentage of the plastic packaging in relation to the sorted plastic waste that is arriving at COREPLA is calculated at 90.3%. This means that 9.7% or 127127 t of the plastic waste that is sorted by COREPLA isn't for plastic packaging. This share is either sent for incineration or energy recovery.



Plastic packaging waste treatment in Italy.
Data source: COREPLA (2020).



Relation of sorted plastic waste treatment between COREPLA and the rest of Italy.
Data source: COREPLA (2020).



Relation of sorted plastic packaging waste treatment between COREPLA and the rest of Italy.
Data source: COREPLA (2020).

4.2 Turin: Plastic Waste Stream Actors

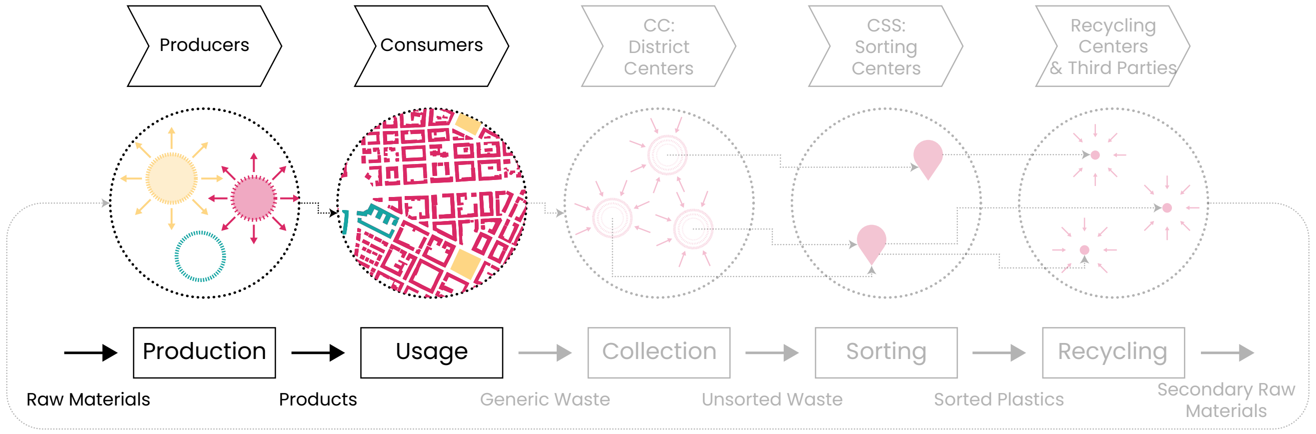
4.2.1 Plastic Production / Plastic Usage

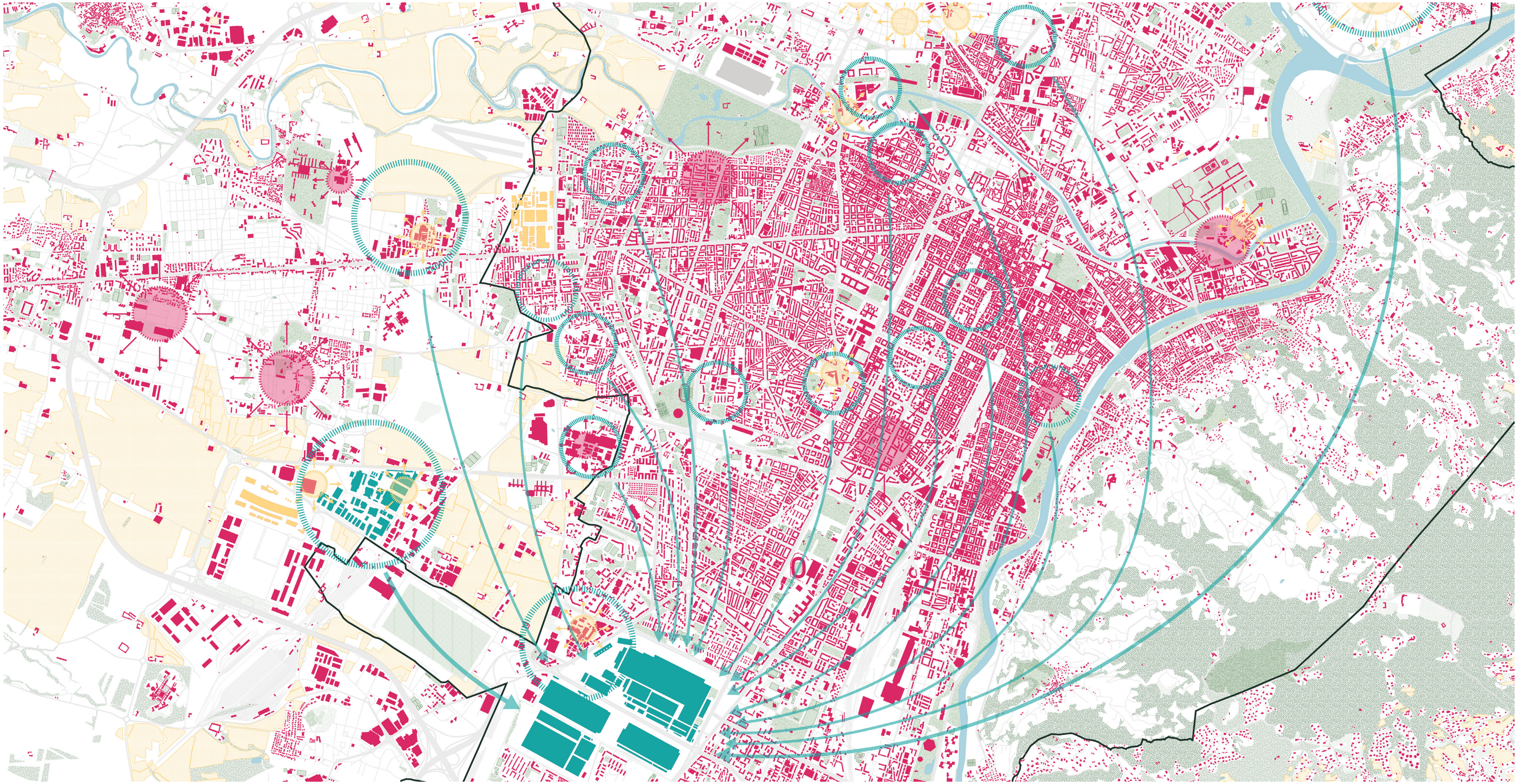
Plastic Production: (Various producers: Packing Plast Italia Sas / Aged / Sigit Spa, etc.)
Plastic Usage: (ANCI – Associazione Nazionale dei Comuni Italiani / Consumers)

The Metropolitan City of Turin population: **2,200,000**

Sorted waste collection by habitant in Piedmont: **24.2 kg/hab./Year**

Data source: Wikipedia / COREPLA (2020).





Turin's Plastic Waste Stream in Italy's Recycling System

Turin's Plastic Waste Stream in Italy's Recycling System

4.2.2 Waste Collection / Waste Treatment

Waste Collection: (CC) Irene Amiat / Waste Sorting: (CSS) Demap, COREPLA / Waste Treatment: Amiat, COREPLA

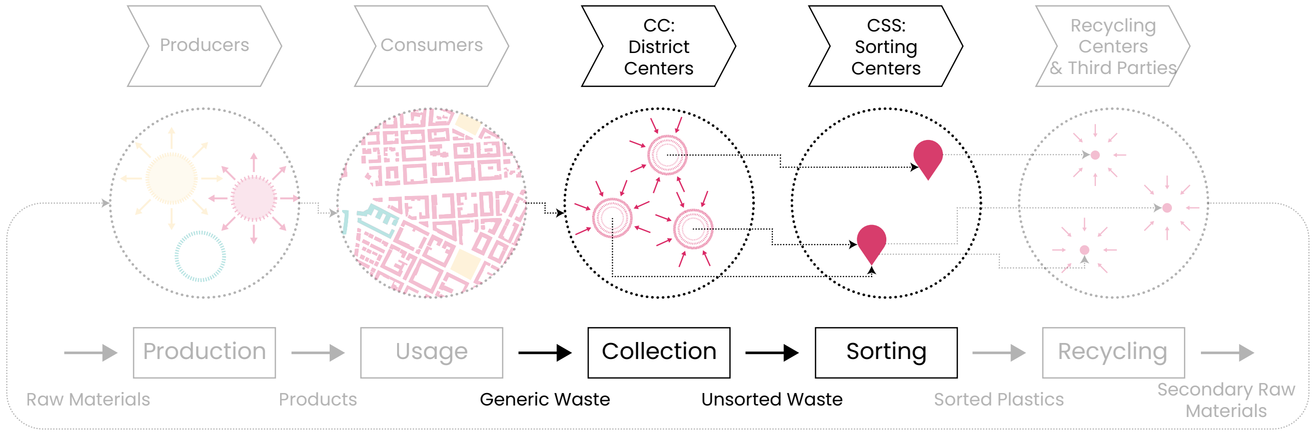
The sorted waste in Turin is estimated by multiplying the inhabitants by the waste sorted per inhabitant. It is then mutliplied by the share (91.1%) being sorted by COREPLA. Then, it is multiplied by the share (95.1%) being recovered, (energy recovery or recycling.)

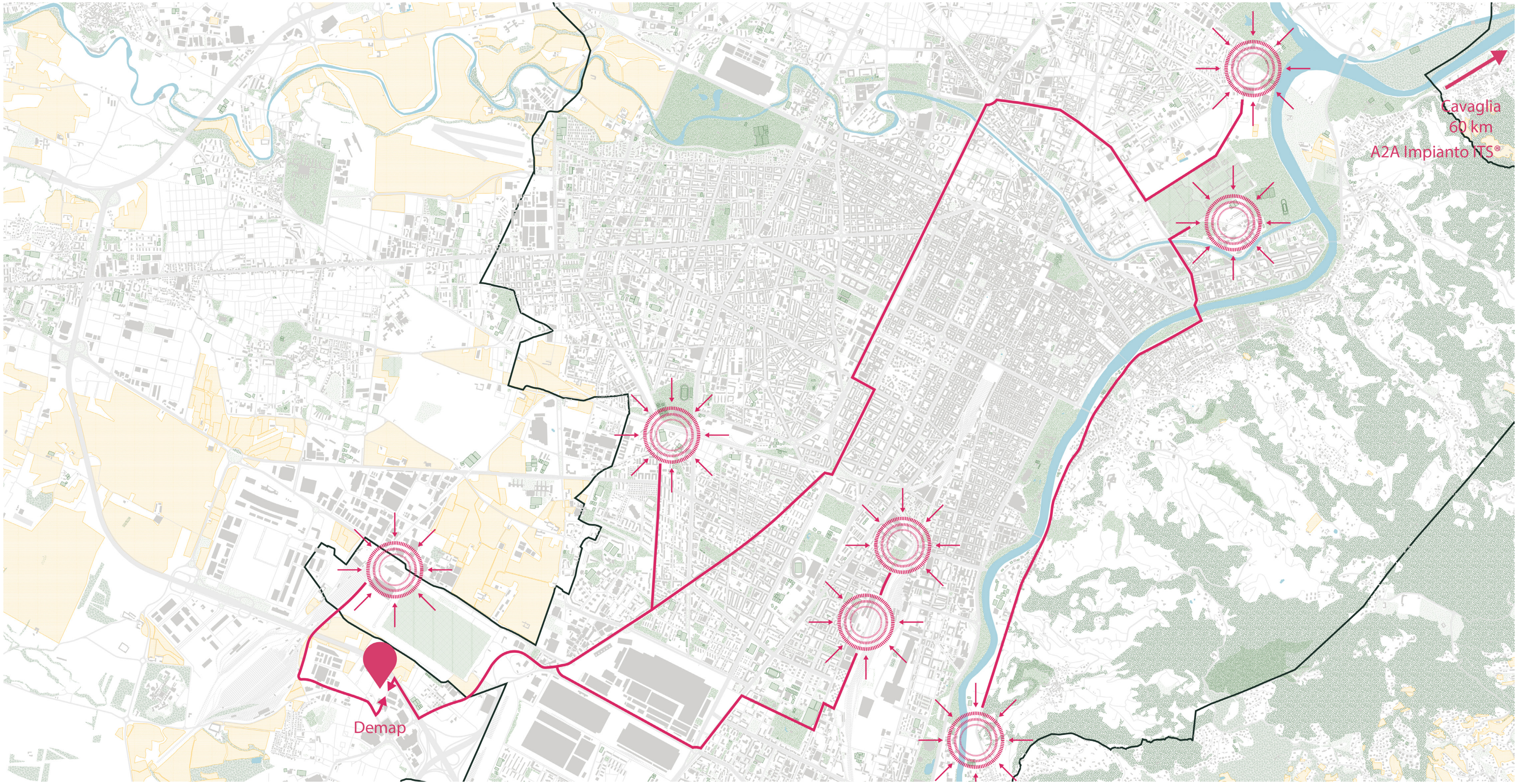
Sorted waste collection in the Metropolitan City of Turin: **53240 t**

Sorted waste collection by COREPLA in the Metropolitan City of Turin: **48502 t**

Recovered waste collection by COREPLA in the Metropolitan City of Turin: **46125 t**

Estimated values - Data source: COREPLA (2020).





Turin's Plastic Waste Stream in Italy's Recycling System

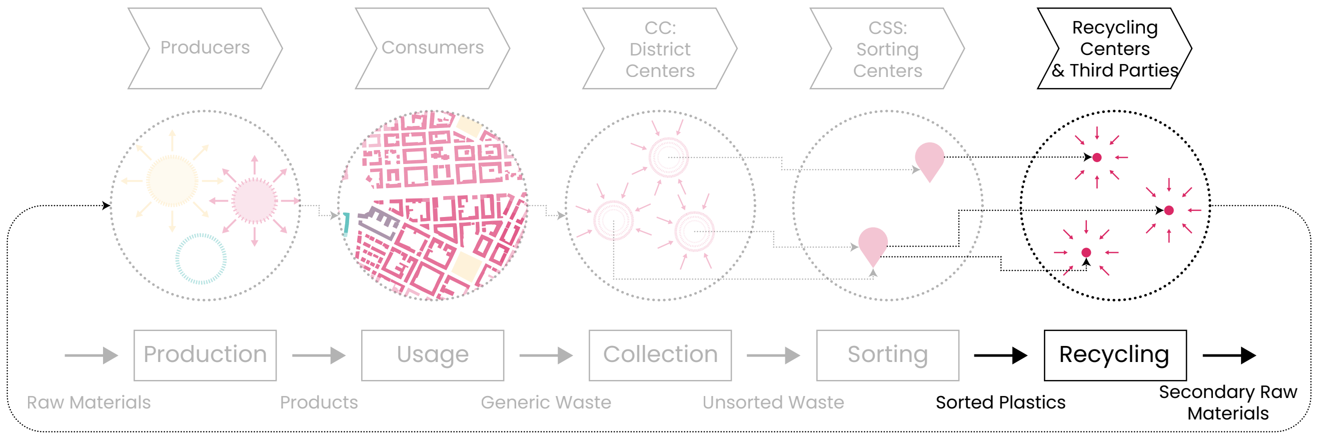
4.2.3 Secondary Markets

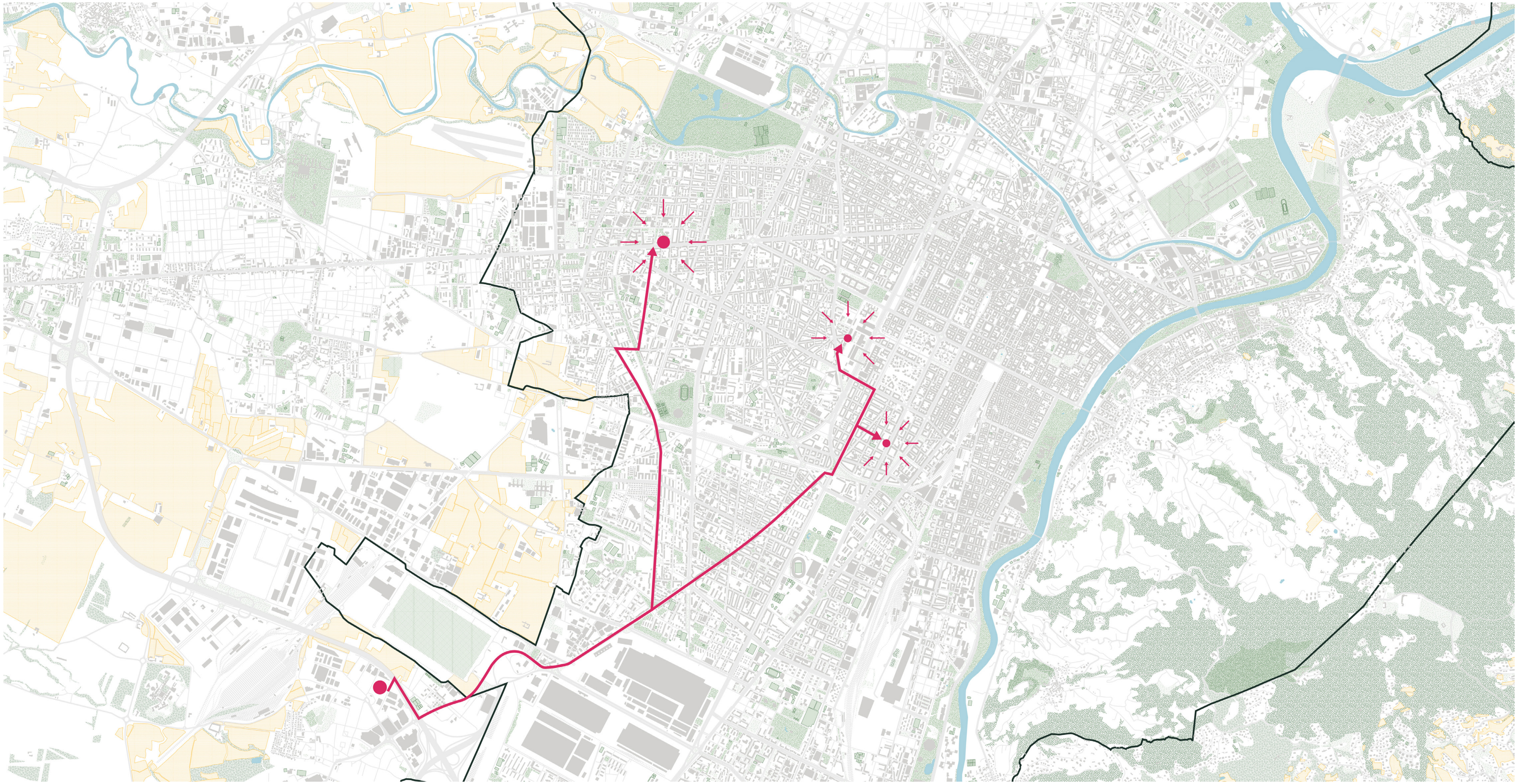
The neutral fraction is sold to third parties that recycle the materials and resell it on the materials' market as secondary raw materials.

The recycled waste collection in the Metropolitan City of Turin can be estimated with COREPLA's recycling percentage data of 47.3%.

Recycled waste collection by COREPLA in the Metropolitan City of Turin:
22941 t

Estimated value - Data source: COREPLA (2020).





Turin's Plastic Waste Stream in Italy's Recycling System

4.3 Turin: Non-Recycled Plastics

4.3.1 End of Life

As previously stated, COREPLA exclusively accepts plastics from packaging due to a CONAI law that requires packaging manufacturers to pay a fee in order to ensure the collection and recovery of packaging sold in the Italian market (extended producer responsibility). As a result, the recycling potential in Italy is not completely seized, as many plastic items are not allowed by CONAI (2018) and, as a result, are discarded during the sorting and selection procedures in the CC and, later, in the CSS facilities.

The packaging constraint prohibits a larger proportion of plastics from being sent for recycling, even though COREPLA offers financial compensation for 14 different types of flows. Outer fractions are defined under the Agreement as everyday goods such as plastic cutlery, toys, construction products, and, more broadly, any object that is not intended to be used as packaging. As a result, it is unnecessarily disposed of in either an incinerator or a landfill.

After the discussion with COREPLA's engineer Davide Pollon we have concluded that it would be interesting to use what COREPLA calls "PLASMIX", a trade name of a by-product. (Not a mix of plastics). All plastics and non-plastics that are in the collection that are not possible to recycle, they are sent to energy recovery, cement production, steel production. Plastics that are today not being recycled, "PLASMIX" includes different types of plastics, (Ex: LDPE, PP, etc.) PLASMIX plastics are safe to use because the sourced packaging plastics are used for domestic purposes.

The share of plastic packaging left over from the selection process of sorting the waste collection that is not mechanically recyclable (cd. PLASMIX), is sent for energy recovery and/or to landfill disposal. It is recovered either by co-combustion in the cement plant or by combustion at the waste-to-energy plants.

75.2% of PLASMIX is transformed into alternative fuel and recovered at cement factories. 43% (+ 2% compared to 2019) was recovered in 2020 by the national cement factories while 32.2% (-1.8% compared to 2019) was used in foreign cement factories. The remaining 24.8% (-0.2% compared to 2019) was sent to waste-to-energy plants, mainly present in the Northern regions of Italy.

During the year 2020, a non-negligible portion of PLASMIX was recovered at the waste-to-energy plants. However, even in 2020 despite the greatest use of the latter in the period March-June due to the closure of cement factories due to the lockdown, there was an overall decrease of the quantity sent to waste-to-energy substantially caused by technical choices of the managers and the various national criticalities. To the share of PLASMIX sent to landfill (direct landfill) are added the quantities of residual waste for the fuel preparation activity. (Indirect landfill).

Research & Development activities during 2020 focused on research projects aimed at increasing both the percentage of products sent for recycling than those destined for energy recovery, helping to develop applications and synergies throughout the supply chain of plastic packaging.

Important project results achieved during the year:

• The enhancement of PLASMIX and of the tank bottom generated by recycling polyolefins:
In 2020 an important collaboration was started with Saipem and with Itea, a company of the Sofinter Group, to evaluate the possibility of enhancing the "bottom of the tank" and the PLASMIX with the oxy-combustion technology flameless for obtaining CO2 and thermal energy.

• The enhancement of flexible polylaminate packaging:
In the second half of 2020, the Consortium has launched a collaborative study with Nestlé and Ecoplasteam to investigate the possibility of recycling mechanically those flexible polylaminate plastic / aluminium packaging which today are intended for energy recovery.

• The RiVending project:
The activities of dissemination of the RiVending project, launched in 2019, for collection and recycling of polystyrene cups and stirrers (used in the automatic distribution of hot drinks) in collaboration with Confida e Unionplast. Despite the difficulties linked to the pandemic, important italian companies have enthusiastically joined this circular economic initiative.

• The depolymerization of PET trays:
Continued efforts in 2020 of verifying the recyclability of PET trays through the use of chemical recycling. Collaboration with the Piedmontese company GARBO made it possible to verify the possibility of transforming these post-consumer packaging in an intermediate product for use in the production of new virgin raw material that can also be used in the sector of food packaging. Following the positive results, the first plant is under development in an industrial scale.

• The Plastic to Chemicals project:
The activity continued also in 2020 in collaboration with Versalis (Eni) and the engineering company SRS for use of pyrolysis technology, where material is exposed to high temperature, and in the absence of oxygen goes through chemical and physical separation into different molecules. The 6000 ton / year pilot plant, foreseen is under construction in Mantua. This process will allow for depolymerization of the Consortium's heterogeneous plastics (PLASMIX) and the production of raw materials to be used in the petrochemical field to produce new plastics.

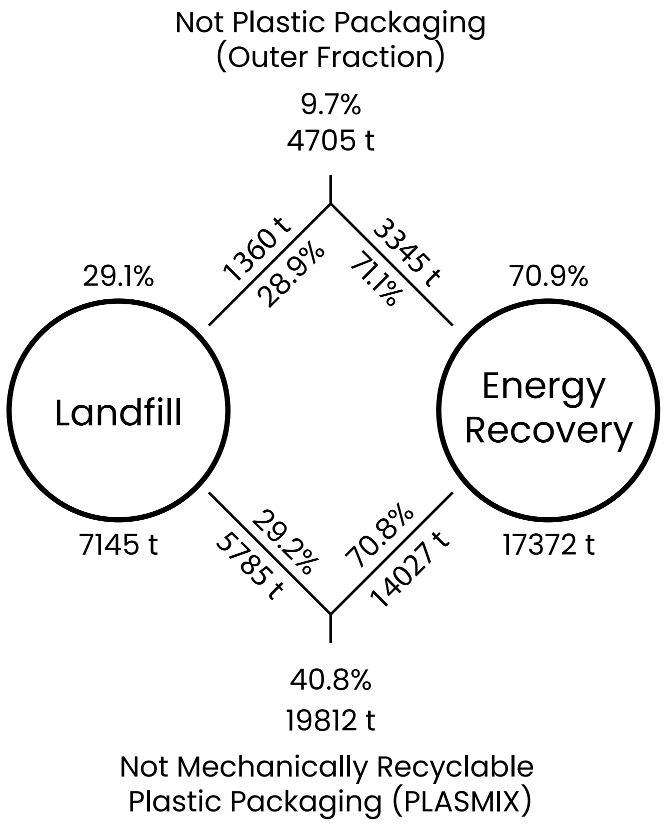
• The Gasification project:
The activity of collaboration with the Eni Group for the study of the technology of gasification to transform PLASMIX into Hydrogen or Methanol. COREPLA has also started a collaboration with Nextchem, del Maire Tecnimont Group, to learn more about the possibility of transforming the PLASMIX in hydrogen and carbon monoxide.

These initiatives try to improve in the areas that can be imporved in the end of life of certain plastics. Generally, they consist of improving the existing plastic packaging waste treatment system, or experiment with new ways to recycle (Chemically). However, most of all these developments revolve around the topic of PLASMIX's treatment. It is important to note that plastic recycling processes each has its own advantages and inconveniences. (COREPLA, 2020)

Plastic recovery process	*Criticisms*
Mechanical Recycling	Loss of qualities. Use of energy and resources. The presence of additives or mixed materials can jeopardize the recycling.
Chemical Recycling	Difficult for some plastics to recover selectively the starting materials. Use of energy and resources. the presence of additives or mixed materials can jeopardize the recycling.

Table 2: Edited by Thierry Ramia.
© Mariotti, N., Ascione, G.S., Cottafava, D., Cuomo, F., (2019).

Turin's plastic waste stream in Italy's context, estimated with COREPLA's data, shows a high percentage (40.8%) of plastic packaging (PLASMIX) not being recycled. This is due to the incapacity of mechanically recycling the PLASMIX with today's system. Moreover, 9.7% of the plastic that the CCs and the CSS of COREPLA in Turin are receiving, are indeed not for packaging purposes, therefore, they are sent to landfills or getting incinerated.



Estimated values from the COREPLA report 2020.

Turin's Plastic Waste Stream in Italy's Recycling System

4.3.2 Types of Plastic

Recently, the past few years have been characterized by the COVID-19 pandemic which involved several actions with a strong impact on the economic sector.

In this context, the reduction in the consumption of plastic materials was relatively contained, due to the consistent growth of the medical and disinfection / detergency sectors, with a decisive relaunch of packaged food.

Even packaging, which is the most important outlet of virgin thermoplastic polymers, showed a trend in contraction. The overall quantity of packaging released for consumption on the national territory is estimated to be equal to 2,198 kt (approx. -5.1% compared to 2019), 43% represented by flexible packaging and 57% rigid packaging.

At the level of polymers, polyethylene is the most widespread, mainly addressed to flexible packaging, where its share reaches 74%. Considerable quantities of consumption also occurs for PET and PP, which are mainly used instead of rigid packaging. Among other materials, the volumes of consumption of biopolymers (especially starch polymers for take-out bags ultralight goods and bags), whose share is around 3.3%.

As regards to the function of packaging, there is a clear prevalence of primary packaging, which covers almost 69% of total consumption, while the secondary packaging (mostly shrink film for bundling) is worth about 7% of the total. Finally, observing the distribution of the released plastics for consumption the clear prevalence comes from the domestic channel, while the quantities coming from the industry and trade channels totaled at around 36% of the sum.

However, it should be borne in mind that, through the various forms of assimilation, a considerable share of packaging destined for industry and commerce ends up "migrating" into municipal waste (eg: Ho.Re.Ca., large-scale distribution and small craft activities).

The interest in the consumption demands of plastics stems from a direct correlation to the types of plastics that end up in waste. This way, an estimation of the types of plastics being recycled and not-recycled can be made by looking at the percentages provided by the public data published by COREPLA.

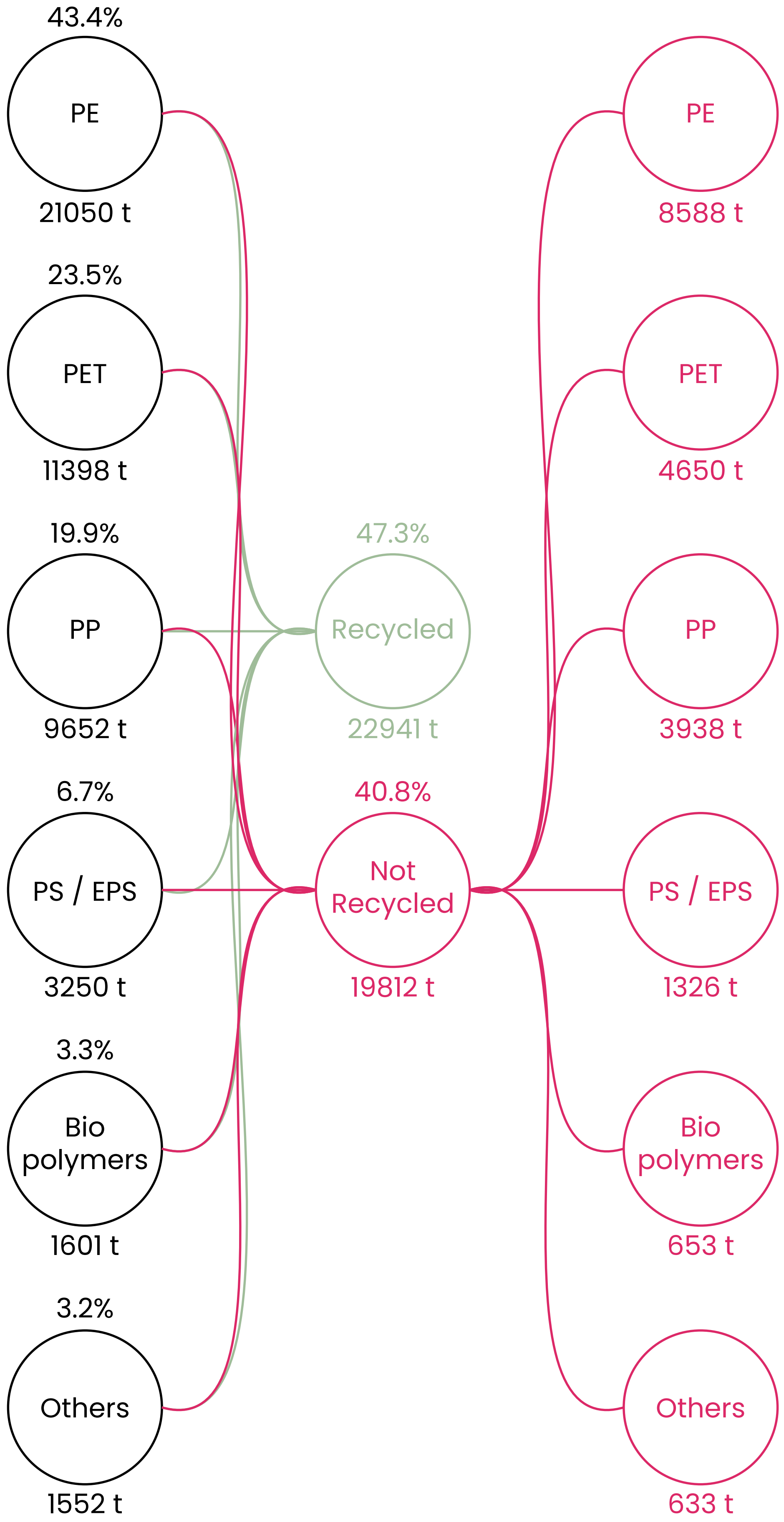
With this data, an estimation could be made out of the yearly supply of plastic packaging (which is directly correlated to the demand of the market) on a national level, scaled down to the Metropolitan City of Turin. This estimation was made by mutliplying the percentage by types of plastics to the estimated amount of sorted waste collection by COREPLA in the Metropolitan City of Turin amounting to 48502 t.

4.3.3 Plastic Properties

Types / Properties	Water Absorption (% wt)	Fire Resistance (%) - LOI	UV Resistance (Qualitative)	Flexural Modulus (GPa)
PE	0.02 - 0.06	17.0 - 19.0	Fair	4.90 - 5.60
PET	0.10 - 0.20	23.0 - 25.0	Fair	2.80 - 3.50
PP	0.01 - 0.10	17.0 - 18.0	Fair	1.00 - 1.60
PS - EPS	0.01 - 0.07	17.0 - 18.0	Poor	2.50 - 3.50
Biopolymer (PLA)	0.16	25.0 - 26.0	Poor	2.70 - 16.0

Table 3: Edited by Thierry Ramia.
© Omnexus SpecialChem.

As discussed in chapter 3, the properties of plastics depend on the type of plastic. From the un-recycled plastics, can be found PE, PET, PP, PS / EPS, Biopolymers and other types of plastics. With using plastic as a component in a composite building material for a facade panel application in mind; the properties of the plastic types shown above, indicate PE as being the most prominent for such use. Furthermore, in the diagram on the right, according to the estimations made from the data provided by COREPLA adapted to the Metropolitan City of Turin, on the percentages of un-recycled plastic types, PE seems to be the most un-recycled. Indeed, PE is the most used plastic packaging type of plastic for domestic use. This renders it the most logical choice for application in our study, it presents reasonably good properties and is abundant.



Estimated values of not recycled packaging plastics by COREPLA in Turin from the COREPLA report 2020.

5. Plastiglomerate as a Building Material

Figure 29: Plastiglomerate.
© Kelly Jazvac.

5.1 Introduction to the Material Driven Design (MDD) Method

Novel materials are constantly being developed as superior alternatives to traditional materials. When a novel material is first introduced to the market, its functional aspect is prioritized and assumed. However, this may not be enough to ensure its financial success and widespread adoption. In addition to its utilitarian assessment, the material should evoke significant user experiences. The material should not only be defined in terms of what it is and what it does, but what it expresses to us, what it elicits from us, and what it compels us to do should play an equal role in its assessment. Industries and material scientists have sought out to designers to steer the creation of materials by experiential goals. Regretfully, there hasn't been a widespread developed tool that is followed to create such materials with experience in mind.

The Material Driven Design (MDD) method invented by Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A. (2015) has been conceived as a response to that lack, it allows to make it easier to conceive materials that consider experiences.

The MDD approach is based on the following assumptions:

- Product experience originates from vast diverse sources. However, the physical experience of a design is arguably the most distinguished one. Intended to shape and effect the entire user experience, materials physical experience, should be considered in any material-driven design project.

- Understanding the material's properties and limits compared to other materials is necessary when designing a material. Experimenting with the material at hand enables that understanding. This experimentation is used as an evaluation process and production analysis embodying all the phases of conception, from the initial interaction to the final product.

• Similar to traditional product design processes; field researching, benchmarking, doing a market analysis, developing design requirements and objectives, concepts, and detailing for the eventual product application are necessary action steps.

These assumptions can be applied following determined steps provided by the method of MDD.

Firstly, the material being considered should be profoundly understood, it can range from which elements the material is constituted of, to where the material can be sourced, the technical properties are also to be inspected at this stage.

Secondly, this step is to try to define the materials' experience wanted from the designer. It implies asking a succession of questions, to clarify the goals of the materials' effect.

Thirdly, at this stage, the new contributor to this materials' experimentation, would look at past contributors who experimented with this material. This would entail, looking at the designers' intents and expectations, the products' actual use, its experience result, the challenges faced and of course the technical properties of that product, in relation to its usage.

Lastly, the designer or new contributor to this materials' experimentation, proposes a new usage for his product, with its own intentions and effects. This proposal would originate from an informed decision after having learned from previous experiences with this material and understood the markets' needs. (Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A., 2015)

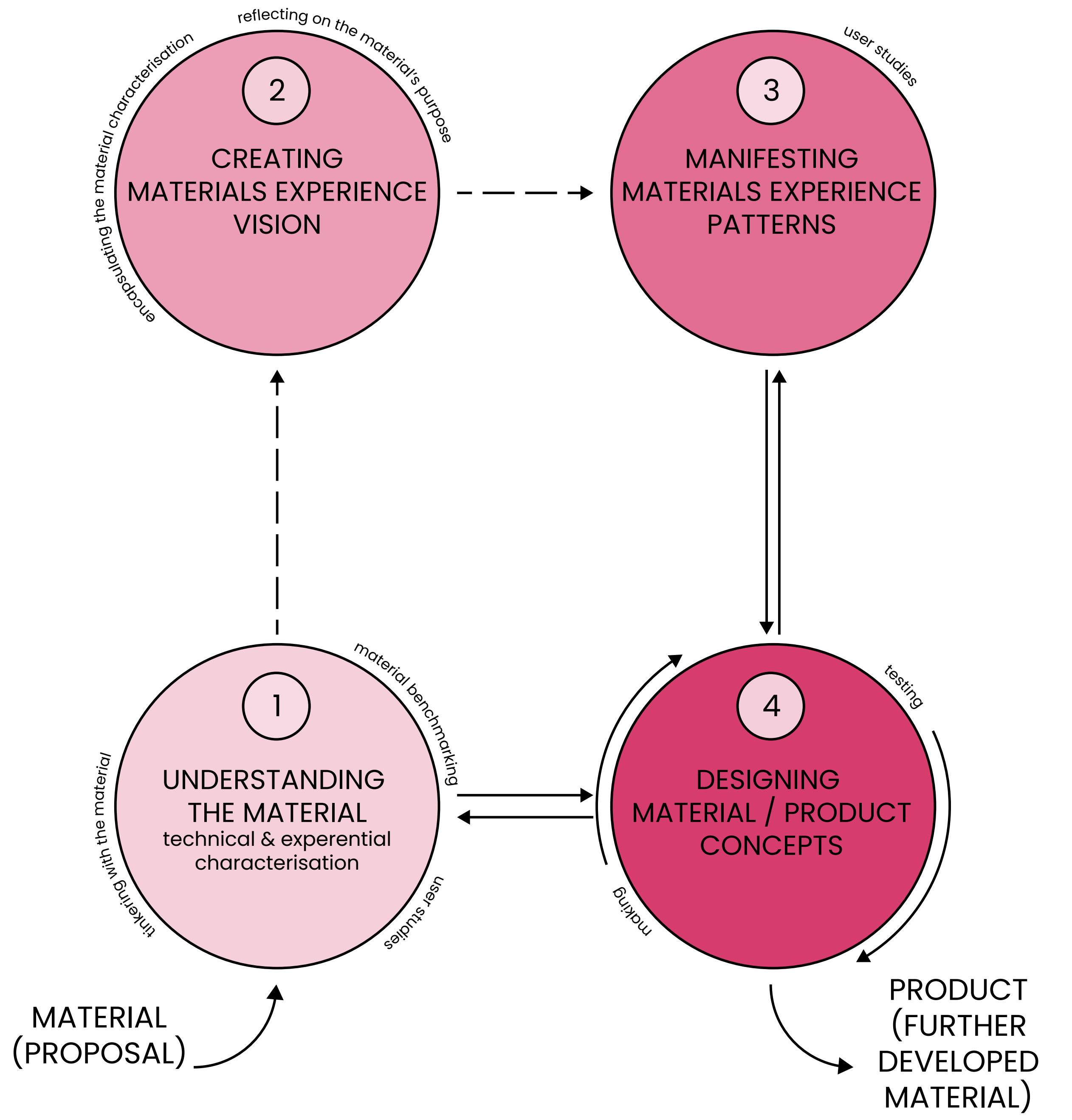


Figure 30: Material Driven Design (MDD) method.
© Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A. [edited by Thierry Ramia]

5.2 Understanding Plastiglomerate

5.2.1 Sources

As we have mentioned in chapter 2 Plastiglomerate is a new type of rock cobbled together with plastic. This new semi-synthetic material, referred to as Plastiglomerate, requires a significant heat-source to form. It formulates once molten lumps of plastic are mixed-in with ambient waste. The material has firstly been documented in Hawaii, due to its coastal and marine volcanoes, offering a perfect formational landscape for its artificially inflicted geology.

Patricia Corcoran, one of the discoverers of Plastiglomerate thinks that we will likely find them "on coastlines across the world. Plastiglomerate is likely well distributed, it's just never been noticed before now." Rendering this material to be locally abundant, such as concrete, made of common materials (cement, water, and aggregate). In Plastiglomerate's case, it can either be sourced from local industrial and plastic wastes of neighboring cities, or distant sources of wastes washed away in the beaches of anonymous coastlines.

Looking at it at different timescales. Plastiglomerate, can both be considered part of geology and merely melted plastic messily assembled with local minerals. Heavy chunks of Plastiglomerate will form over time, mixing with denser elements and descending to the sea floor, leaving it embedded in the geologic record. The plastic can be found in two ways: by having vain-like qualities, streaking through other rock deposits, and binding together the various ingredients required for Plastiglomerate production. Liquified plastic can be flow into big rocks to fill gaps and bubbles.

It doesn't seem like much of a stretch to suggest that our landfills are also acting like geologic ovens: baking huge deposits of Plastiglomerate into existence, as the deep heat and occasional fires found inside landfills catalyzes the formation of this new rock type. Could deep excavations into the landfills of an earlier, pre-recycling era reveal whole boulders of this stuff? Perhaps. (Manaugh, G. 2014).

Plastiglomerates could thus be seen as something like an intermediary stage in the long-term fossilization of plastic debris, a glimpse of the geology to come. (Manaugh, G. 2014).

Plastiglomerate firstly discovered in Kamilo Beach, Hawaii, has been studied by Patricia L. Corcoran, Charles J. Moore, and Kelly Jazvac, consequently, the presented results of Plastiglomerate constituents are locally bound to Kamilo Beach's context.

Plastic degradation is a slow process that can occur mechanically, chemically (thermo- or photo-oxidative), or biologically (to a lesser extent).(Kulshreshtha, 1992; Shah et al., 2008; Cooper and Corcoran, 2010 as cited in Corcoran, L.P., et al 2014). Plastic has been projected to last hundreds to thousands of years in the environment, while longevity can increase in cool regions and where debris is buried on the ocean floor or under sediment.

Sunken plastic trash has a good chance of surviving and eventually becoming part of the rock record due to low water temperatures and less UV light exposure at greater depths within and below the photic zone. Plastic debris, such as resin pellets, pieces, and expanded polystyrene up to 11 mm in diameter, can be found in the top 5 cm of beach sediment. (Kusui and Noda, 2003 as cited in Corcoran, L.P., et al 2014). Furthermore, plastic waste could be found at sediment levels down to 1 m depth while researching polycyclic aromatic hydrocarbons in pellets. (Fisner et al. , 2013 as cited in Corcoran, L.P., et al 2014)

However, no visible loose plastic fragments were found at depths >10 cm in sand on Kamilo Beach, Hawaii. Given the beach's constant exposure to the northeasterly trade winds, much of the small (<10 cm), lightweight plastic debris is blown to the backshore environment, where it becomes trapped in vegetation. On a beach as dynamic as Kamilo, preservation of plastics in the sediment column could occur where trapped sediment is covered with sand or where a polymer is

Figure 31: Marine debris along the southeast coast of Ka'ū, island of Hawai'i (18°55'39.1"N 155°38'59.6"W).
© Benjamin Weinger.

combined with a much denser material. The results of this density increase, where great quantities of melted plastic have mixed with the substrate to create new fragments of much greater density, herein referred to as "plastiglomerate" were observed on Kamilo Beach. (Corcoran, L.P., Moore, J.C., and Jazvac, K. 2014)

The Hawaiian Islands act as sinks for plastic waste due to their placement within the North Pacific subtropical gyre (Moore, C.J., 2008). The major Hawaiian Islands' eastern and southeastern windward shorelines, are considered the preferential deposition of marine waste due to the anticyclonic flow of the surface ocean currents within the gyre (Corcoran et al., 2009; McDermid and McMullen, 2004). Hence, Kamilo Beach, on the southeastern corner of the Hawaiian island, is known for accumulating the largest amount of marine waste (Moore, C.J., 2008).

Derelict fishing gear, including nets, oyster spacer tubes, and buoys; food and drink containers; resin pellets; and multicolored shards or "plastic confetti" are examples of typical plastic waste. Kamilo Beach's main stretch is around 700 meters long, and its northern end is marked by a rocky promontory that juts out 300 meters into the ocean during low tide. The beach is only accessible by four-wheel drive vehicle, and the nearest paved road is 12 kilometers away. Because most tourists camp for extended periods of time and make fires for cooking and warmth, the beach's remoteness plays a significant part in the establishment of a prospective plastiglomerate marker horizon. Furthermore, regular, beach clean-ups are difficult to organize. (Corcoran, L.P., Moore, J.C., and Jazvac, K. 2014)

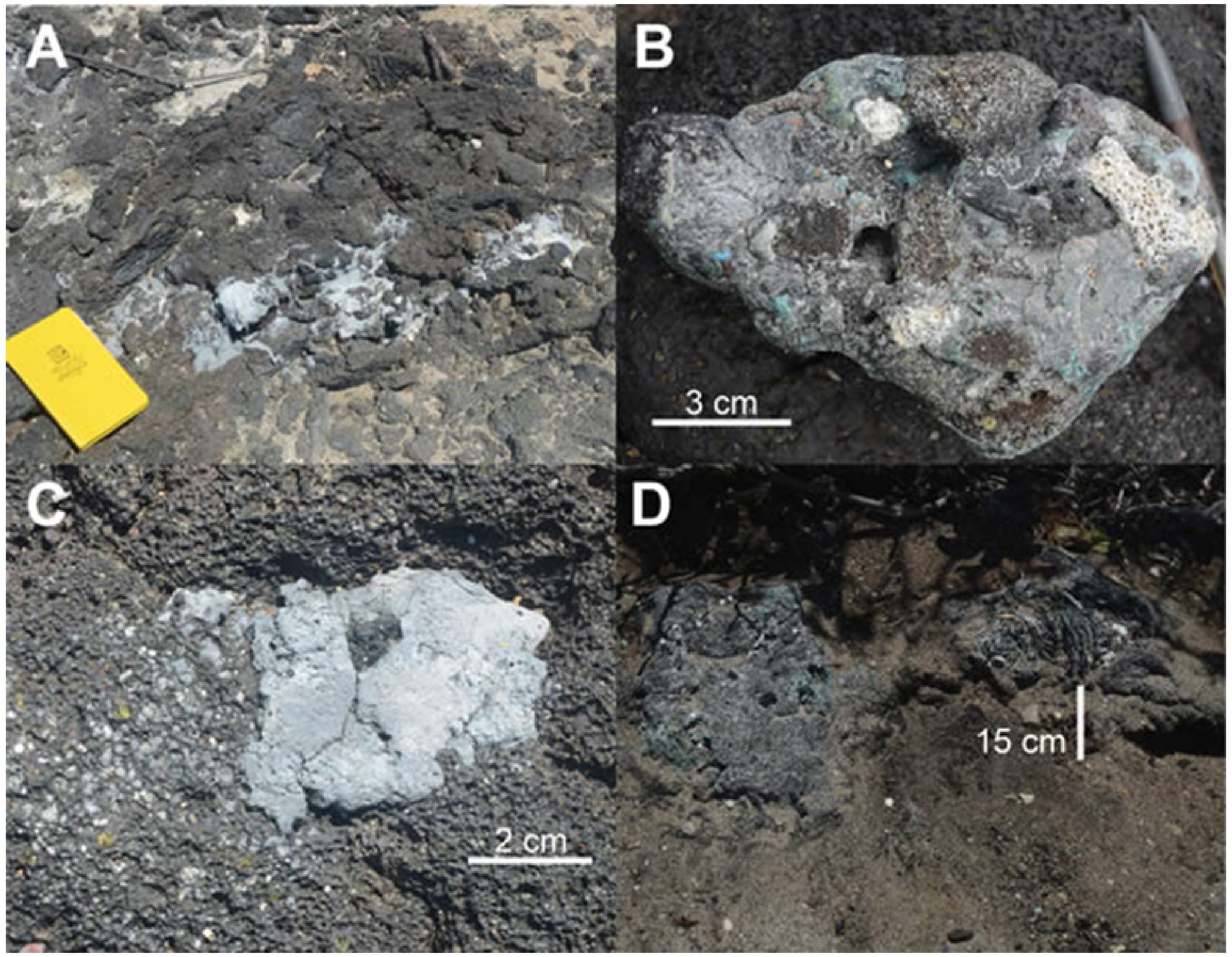
Plastiglomerate is classified into two types: in-situ, in which plastic is stuck to rock outcrops, and clastic, in which basalt, coral, shells, and local woody waste are cemented in a plastic matrix with grains of sand (Figures 32A and 32B). Fishing nets, pipes, bottle caps, and rubber tires were among the partially melted polymers clinging to basalt outcrops. Plastic amygdales were formed when molten plastic filled vesicles in volcanic rock (Figure 32C). The biggest in-situ plastiglomerate surface exposure found by the team was 176 x 82 cm, which was only visible after 15 cm of beach silt was removed (Figure 32D). Clast plastiglomerate particles located closer to the water and along the strandline were rounded due to abrasion (Figure 32B). In the 205 sampled fragments at Kamilo Beach could be found different combinations of plastic, coral pebbles, woody waste, basalt pebbles, and sand (including shell) (Figure 33A). (Corcoran, L.P., Moore, J.C., and Jazvac, K. 2014)

Out of the sampled fragments found at the beach, the smaller plastiglomerate formation by size smaller than 4 cm were mainly constituted exclusively of sand and plastic. Larger formations, included in addition basalt pebbles and woody debris. This difference could be due to the weathering of organic woody waste and charcoal from bigger fragments, leaving the smaller ones without organic components.

From the distinguishable plastic types found in plastiglomerate, the scientists were able to indentify netting and ropes plastics, pellets and partial packaging plastic products, pipes, lids and "confetti" (Figures 34A–34D). The "confetti" was the most common one to be found, as the original products such as containers remain intact (Figure 33B). In 22% of all fragments, partial containers and lids were recognized and preserved. Approximately 20% of the samples revealed indications of fishing-related waste, such as ropes, netting, nylon fishing line, and oyster spacer tube remains. (Corcoran, L.P., Moore, J.C., and Jazvac, K. 2014)

Plastiglomerate found at Kamilo Beach were buried in sand and organic waste, and some were even caught between the vegetation. This shows preservation potential in the long run, in the geological footprint.

Although Hawaii is a volcanically active island, the known places of flowing lava over the last century do not correspond to Kamilo Beach. As a result, the plastiglomerate we found on Kamilo Beach could not have formed as a result of hot lava interacting with polymers. These plastiglomerate fragments were created anthropogenically. In this regard, Kamilo Beach exemplifies an anthropogenic activity (burning) in



Figures 32: Characteristics of the two types of plastiglomerate. (A) In situ plastiglomerate wherein molten plastic is adhered to the surface of a basalt flow. Field book is 18 cm long. (B) Clastic plastiglomerate containing molten plastic and basalt and coral fragments. (C) Plastic amygdales in a basalt flow. (D) Large in situ plastiglomerate fragment. Adhered molten plastic was found 15 cm below the surface. Note the protected vegetated location.
© Patricia L. Corcoran, Charles J. Moore, Kelly Jazvac.

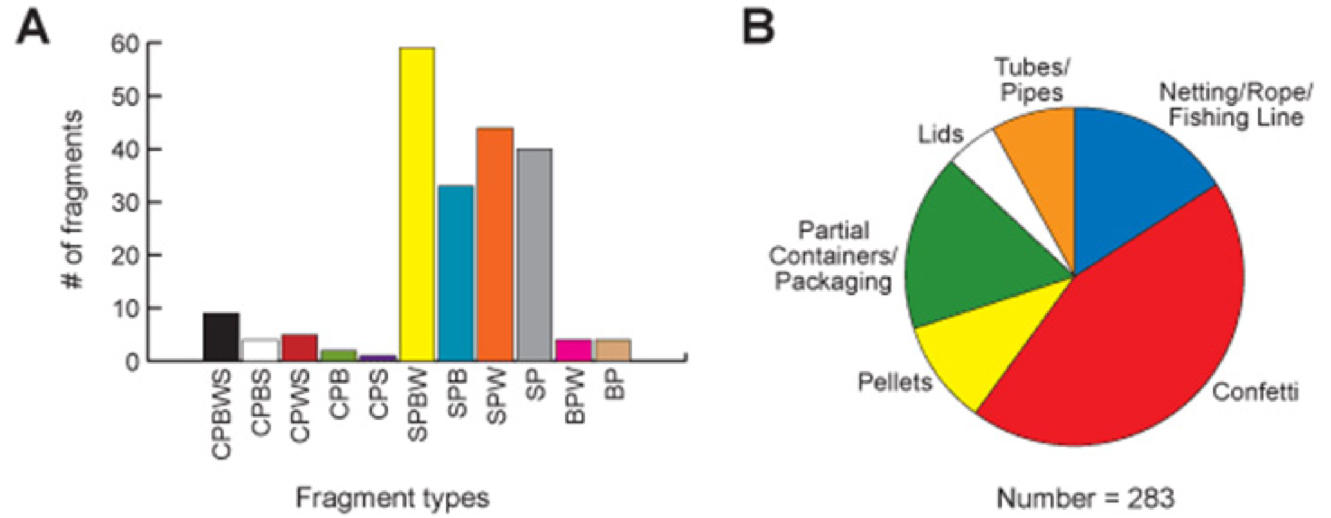


Figure 33: Diagrams illustrating the types of plastiglomerate and relative percentages of adhered plastic fragments. (A) Material composing the sampled plastiglomerate: B—basalt clasts; C—coral fragments; P—plastic; S—sand and sand-size shelly fragments; W—woody debris. (B) Pie diagram showing the relative abundance of different plastic products in plastiglomerate.
© Patricia L. Corcoran, Charles J. Moore, Kelly Jazvac.

response to an anthropogenic problem (plastic pollution), resulting in a distinct Anthropocene era marker horizon. Although the plastiglomerate on Kamilo Beach is the result of campfires, it is possible that the global expanse of plastic waste might lead to similar deposits in places where lava flows, forest fires, and extreme temperatures occur. (Corcoran, L.P., Moore, J.C., and Jazvac, K. 2014)

5.2.2 Properties

The bulk density of 20 clastic plastiglomerate fragments collected from Kamilo Beach was measured by the researchers. The bulk density ranged from 1.7 to 2.8 g/cm^3, with fragments rich in basalt pebbles having the highest values. The measured bulk densities reveal that plastiglomerate has a higher chance of being buried and retained in the rock record than plastic-only particles, which typically have densities in the 0.8–1.8 g/cm^3 range. (Kholodovych and Welsh, 2007 as cited in Corcoran, L.P., et al 2014).

Plastiglomerate's properties vary according to the location of origin. It is not a fixed material in its constituents. Moreover according to Corcoran its various forms of heterogeneity could be found anywhere in the world. It is therefore important to note that when studying the properties of naturally sourced or even artificially sourced plastiglomerate with the prospect of using it as a building material, the question of plastiglomerate's material sourcing has to be determined.

As we have seen, the plastics that can be found in plastiglomerate are the ones washing out of the oceans, and settling at the shorelines. Plastics accumulated from our waste that can be found in the gyres in the ocean to some extent reflect our plastics usage. However, the ones found in the gyre do not translate literally the ones we consume. That is to say that it depends on the rigidity and size of the plastic product, the type of plastics whether it is UV resistant or not and of course its water absorption properties.

With PE at 36% being the most common nonfiber plastic, followed by PP at 21%, and PVC at 12%. PET, Polyuréthane (PUR), and Polystyrene (PS) each accounting for 10% of total nonfiber plastics manufacturing. Polyester accounts for 70% of total polyester, polyamide, and acrylic (PP&A) fibers output, the majority of which is PET. These seven types of plastics are responsible for 92% of all polymers ever produced. Packaging has accounted for around 42% of all nonfiber plastics, with PE, PP, and PET being the most common. The building and construction is the second largest consumer sector, which consumes 69% of all PVC, amounting to 19% of all nonfiber plastics. (Geyer et al., 2017 as cited in Corcoran, L.P., et al 2014).

To some degree, plastiglomerate found naturally has in its formation the above mentioned types of plastics, factoring in the variances mentioned related to the plastics properties and initial usage. Furthermore, as discussed by the discoverers of plastiglomerate, a big percentage of fishing-related plastics can be found. Hence, with this heterogeneity, a specific analysis of plastiglomerate's properties cannot be assessed. This is without mentioning the differences between the properties of the different types of plastics themselves.

Depending on the location of its settlement, plastiglomerate includes pieces of a range of types of wood, sea sand, basalt, coral fragments and miscellaneous objects, altering once again the material's properties.

For properties assessment purposes we can broadly define the main elements composing plastiglomerate as molten plastics and aggregates, variating in grain size as coarse, medium and fine.

Plastiglomerate found in nature, is a location-dependent material with a lot of factors weighing in. It would therefore be logical with the prospect of using it as a building material, to replicate it indoors, in a lab in a controlled environment and to source the materials locally from recycling plants. This way, the artificially fabricated plastiglomerate material would be within the standards of building materials, sustainably sourced and safe to use.

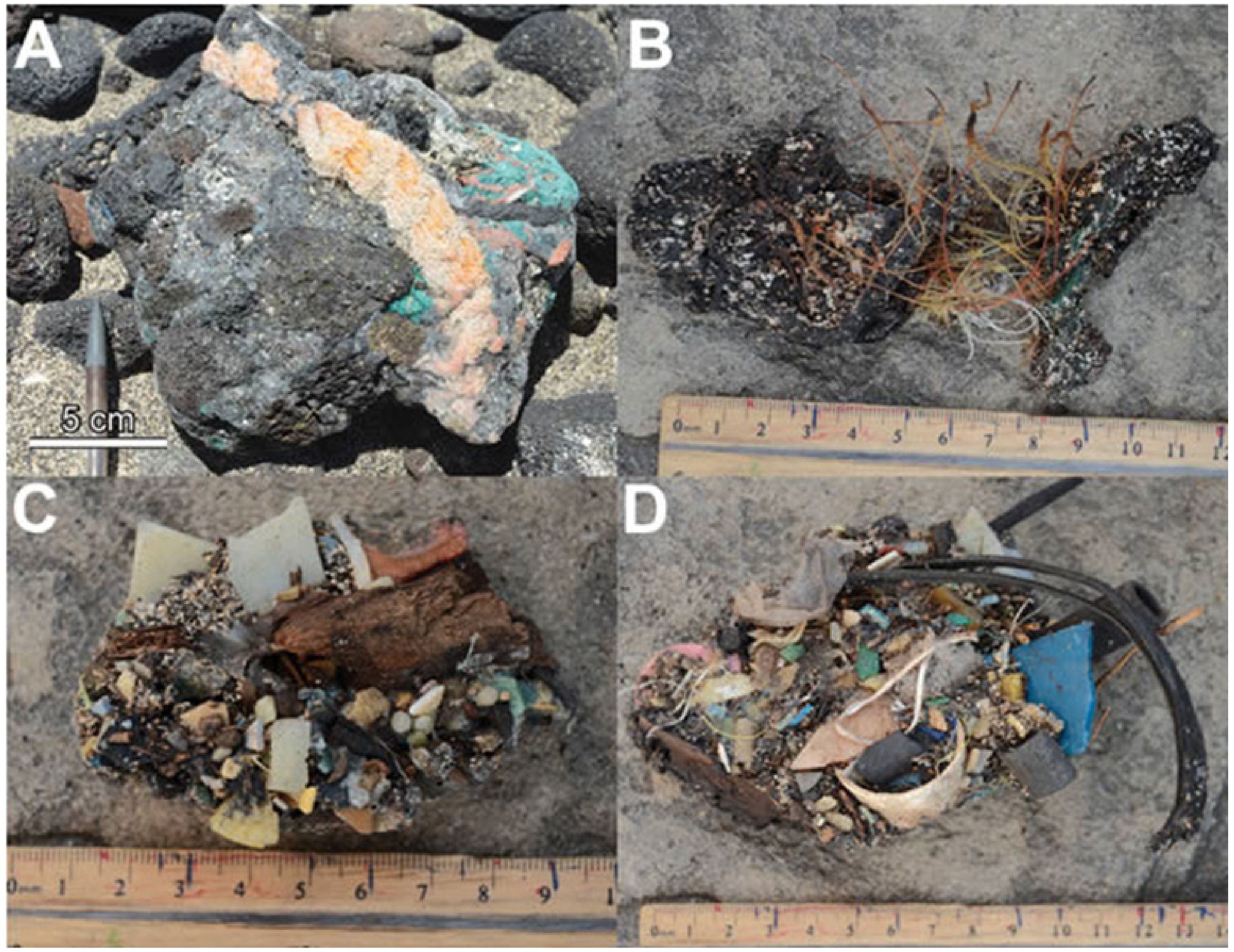


Figure 34: Photographs of clastic plastiglomerate on Kamilo Beach. (A) Subrounded fragment containing basalt clasts, molten plastic, yellow rope, and green and red netting. (B) Portions of black and green plastic containers adhered to basalt fragments and connected by netting. (C) Fragment containing plastic pellets and "confetti" with woody debris. (D) Adhered mixture of sand, black tubing, a bottle lid, "confetti," netting, and part of a plastic bag.
© Patricia L. Corcoran, Charles J. Moore, Kelly Jazvac.

5.3 Creating Plastiglomerate's Experience Vision

In this second step of the MDD method, the designer reflects on the overall material characterisation. This step entails answering questions to define the Materials Experience Vision which helps determine the expected goals.

Which may accommodate various statements that could be interpretative (e.g., the material will express naturalness), affective (e.g., the material will surprise people), or performative (e.g., the material will require delicate use). In addition, the material within a broader context may be defined (e.g., the material will make people aware of their consumption patterns; the material will make people to appreciate products made of 'waste' materials, etc.) (Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A., 2015)

• What are plastiglomerate's distinct technical/experienced characteristics that will be highlighted in the final application?

Plastiglomerate's heterogenous appearance gives it its uniqueness quality. The constituents have a story to tell about their origin. Plastiglomerate registers where it came from, the ecology of its provenance. Hence, the notion of material as medium.

• Where would the material have its most impact and make a positive difference?

Cities function as bubbles for human civilisation. They protect their citizens from the reality of the environmental consequences they have. The use of Plastiglomerate on a very visible façade in a dense city, would attract the most attention and would therefore have the most reactions.

• How would people interact and react with the material within its context of application?

The material's appearance in the midst of the city would stand out. It would cause a shock reaction from the citizens. They would question its presence and origins, and finally understand what message its trying to emanate. The tactile sense of roughness would add to the uniqueness quality and remind the touchers of nature's perfect imperfections. They would thus feel a connection linking them to nature, and hopefully initiate a positive protective reaction on their daily habits in regards to nature.

• In its contribution, what differentiates this material from others? In which sense is it better than alternative options?

Pragmatically, plastiglomerate would be sourced from local non-recyclable plastics and uncollected fine aggregates from the construction and demolition waste (C&DW) which would substitute the scarce sand traditionally used for building materials. Hence, the product proposed would offer an alternative to reuse or recycle the dismissed fractions of waste. Furthermore, its heterogenous aesthetic would offer an appealing alternative to pale and homogeneous facade panel options.

• What would it elicit from people (affective level)?

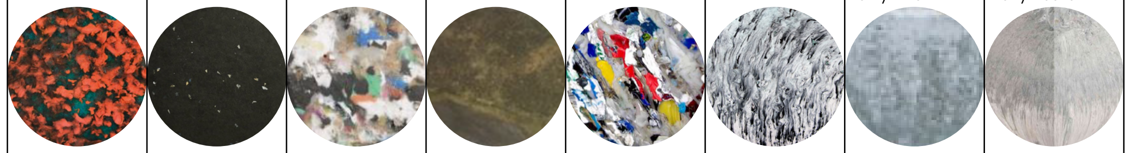
This plastiglomerate product would awaken the otherwise dormant ecological consciousness instilled in people. When seen in practice, it would also encourage other designers / architects to work with these new semi-synthetic materials in innovative and sustainable ways.

• What would it make people do (performative level)?

Producer of this product would be engaged to use un-recycled materials that would otherwise go to waste. On the users level, it would lead to behavioural changes, resulting in carefulness, in better recycling habits.

• What would be the role of the material on a larger scale, such as society, planet?

Looking at it at a broader scale, this material wishes to reduce plastic waste globally, figure out smart new ways to reuse them. As a society, it hopes to spark the Anthropocene-awareness of people, without startling them while simultaneously presenting possible solutions.



	Coral Reef The Good Plastic Company	Charcoal Smile Plastics	Plastiglom-erate Veronika Geiger	Silica Plastic Block Rhino	ByBlock ByFusion	Post Rock T+E+A+M	Plastic Concrete Henry Miller	Pretty Plastic Tile Pretty Plastic
	Recycled coral pink PET plastic and a lagoon-blue PS plastic	Reclaimed medical equipment, and recycled PET from food packaging.	Recycled HDPE plastic mixed with sand binded with sodium silicate	Plastic waste (18%-25%), foundry dust (75%-80%) and coarse sand waste (2-5%)	Recycled mixed plastics	Recycled mixed plastics	Grinding landfill-bound plastic waste mixed with portland cement	Made of old window frames, downspouts, and rain gutters
Applications								
Decorative	yes	yes	yes	no	yes	yes	no	yes
Structural	no	no	yes	yes	yes	no	yes	no
Indoor	yes	yes	no	yes	yes	no	yes	no
Outdoor	no	no	yes (Temporary)	yes	yes	yes	yes	yes
Experiential qualtities & emerging experiential issues								
Imperfections	no	no	yes	yes	yes	no	yes	yes
Heterogeneity	high	medium	very high	low	very high	very high	low	medium
Porosity	none	none	low	low	high	none	low	low
Roughness	none	none	medium	medium	very high	none	medium	low
Durable (over time)	yes	yes	yes	yes	yes	yes	yes	yes
Sources visibility	high	low	very high	none	very high	medium	none	medium
Uniqueness	very high	high	very high	low	very high	very high	low	high
Multicoloured	yes	no	yes	no	yes	yes	no	no
Naturalness	high	very high	low	very high	very low	very high	medium	high
Interactivity	very high	medium	very high	none	very high	very high	low	high
Other emerging issues in design								
	Underwater ecosystem protection by re-using post-industrial waste	Circular economic model. Plastic can be part of a green future	New stone type called Plastiglomerate evidence of the Anthropocene	Develop and establish waste recovery and energy saving solutions as social responsibility	Possibility to convert all types of plastic waste into a building material	Use plastic waste for an alternative high-end rainscreen product	Scarcity of natural sand used for the construction industry	Reusing waste can be beautiful

Table 4: Material benchmarking for plastic waste composite materials.
© E. Karana , B. Barati, V. Rognoli, and A. Z. van der Laan. (Adapted by Thierry Ramia)

5.4 Manifesting Plastiglomerate's Experience Patterns

At this third step of the MDD method, the prospective contributor of the development of the material at hand, learns from the experiences of previous contributors. This step looks into the different uses experimented with this material, reviews the behaviour of their relating properties, and last but not least, understands the user-experience differenciating from an application to another.

At the end of this phase, the designer is expected to summarise the findings of the study, to use their own intuition to interpret the findings, and formulate the relationships between the formal properties of materials/ products and the explored meanings. They can also find other meanings/ values/associations, which are stated by participants to describe the explored meanings. The designer is expected to draw their own conclusions, which they think relate to the attribution of the intended meanings to materials. (Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A., 2015)

The few cases of using Plastiglomerate in the architectural world, (Veronika Geiger's and T+E+A+M projects) teaches us that, to use this material commercially it would have to be created by mimicking the geological process of making plastiglomerate at a smaller scale: erosion, heat, pressure, melting, and mixing.

The project entitled "Plastiglomerate" made by Veronika Geiger with the collaboration of senior researcher Yang Zhang with her students at the Technical University of Copenhagen in the Department of Manufacturing Engineering. The workshop intitled "Experimental Plastic Technology" studied plastiglomerate to be used as bricks for a bench installation.

The project experimented with mixtures of recycled plastics and sand with different types of plastics to try to find the most well-composed brick. Various ratios have been tested to reach the best mechanical properties alongside their aesthetic appearance.

The following information of Chang, X. et al (2018) has been shared by Mrs. Veronica Geiger, it is the report made by the students at DTU under the tutorship of material scientist Yang Zhang.

Three focus points have been designated to insure a good performance of the bricks.

1) Find a process of brick making, to be able to produce 100 useful bricks.
2) Find the acceptable compressive strength of the brick according to the American standards, knowing that the material would have to endure people's weight when sitting on the bench.
3) Water absorption ability was tested, due to the installation being in an outdoor setting with exposure to rain.

The experiment has followed the ATSM standards ATSM C62 and C67. ATSM C62 is used for specifiying the brick requirements for structural and non-structural masonry application. ATSM C67 is used to define the water absorption and compressive strength. However, the study of creep resistance has not been carried out due to the short period of 3 weeks given for this academic research.

The types of Plastics used for the experiment were HDPE, PP, Household plastics, and a carbonized mix including plastics. These different types of polymers are used for different applications and therefore have different strength to density ratios and properties such as their melting points. These polymers react differently, they melt at different temperatures.

HDPE has a low density of 0.93 to 0.97 g/cm3 and a high tensile strength. It can withstand temperatures of up to 120°C and a variety of chemicals. it is commonly used for shopping bags, food containers, trays, hinges, and chopping boards, etc.)

PP is robust and semi-rigid. With a density of 0.93-0.95 g/cm3, it is resistant to heat, chemical, and fatigue. (It's used in film packaging, furniture, and housewares, etc.)
Household plastics are made up of a variety

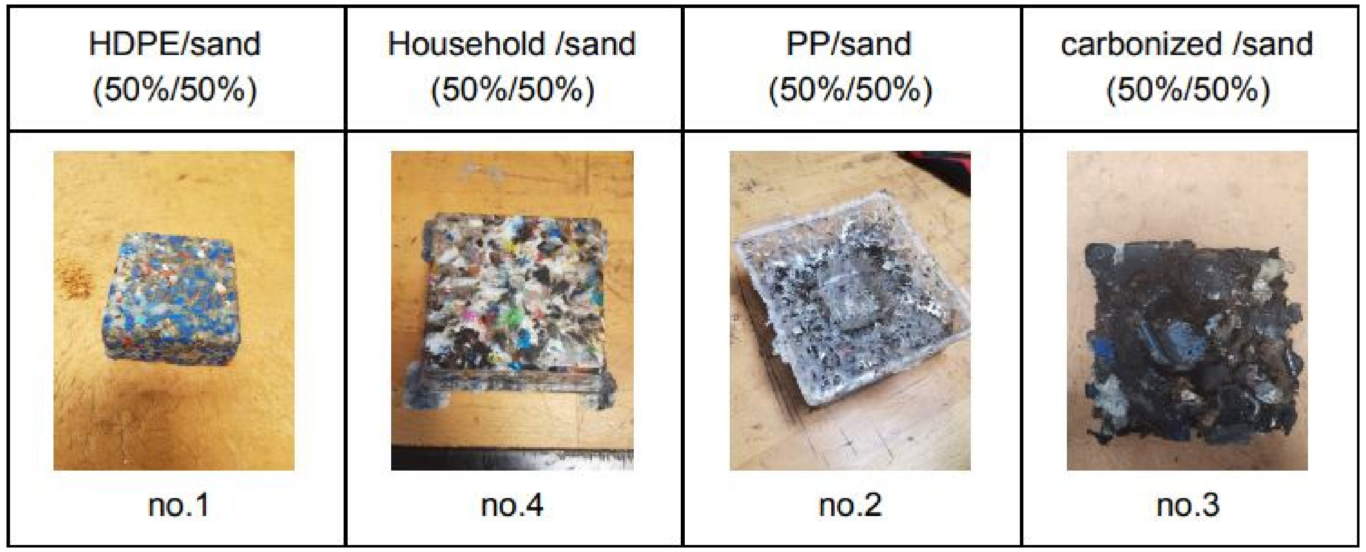


Figure 35: Different Plastiglomerate brick compositions.
© DTU Report by Chang, X. et al (2018). Plastiglomerate. *41738 Experimental Plastic Technology.*

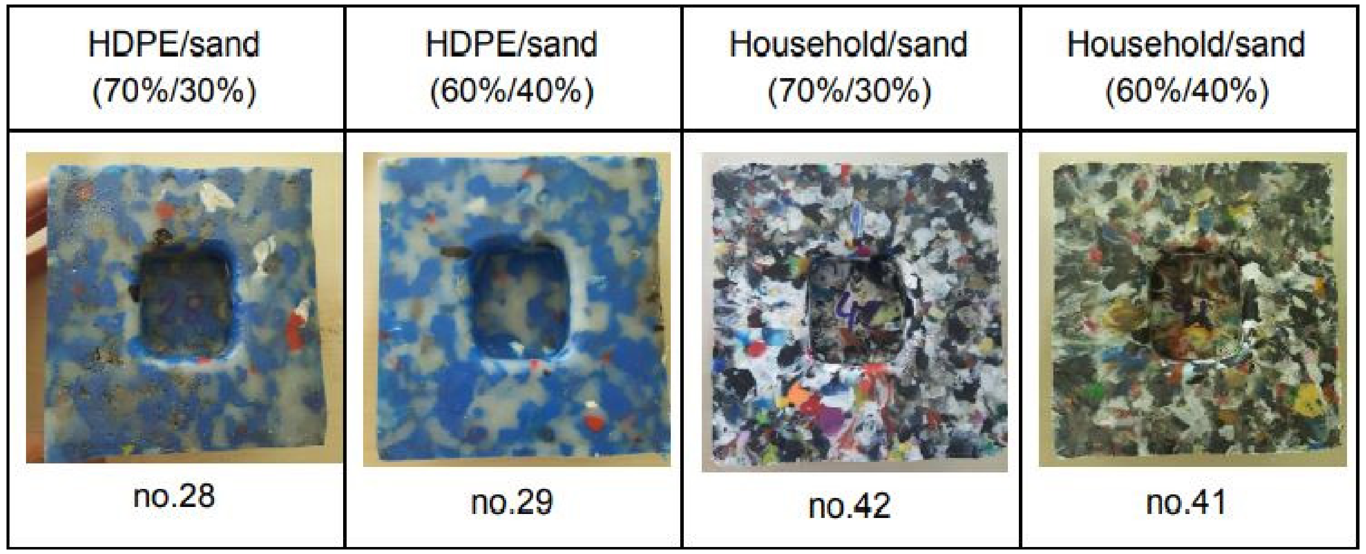


Figure 36: Different ratios of HDPE bricks and Household Plastics bricks.
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Plastiglomerate as a Building Material

of plastics, with PET, PP, HDPE, and LDPE accounting for the majority. As a result, this type has unique qualities and is consequently more difficult to work with.

- Water Absorption Test:

The bricks have been ranked according to the water absorption. This tests the long-term assessment of stability and performance under defined conditions. In the soak test, three samples of each mix were evaluated. The samples were dried for at least 24 hours in the laboratory. After measuring the dry mass Wd, the samples were immersed in cold water in a bucket (30ºC) for 24 hours. The bricks were wiped dry and weighed within five minutes of surfacing after being removed from the water.

The cold-water absorption % was then determined by using eq. 1:

Absorption % = 100(Ws - Wd) / Wd

where:
Wd = dry weight of the specimen
Ws = saturated weight of the specimen after submersion in cold water.

The specimens were then immersed in cold water for 1 hour before being placed in a pot of boiling water. The bricks were wiped dry and weighed within five minutes of surfacing after being removed from the water. The percentage of hot water absorption was then calculated using eq. 2:

Absorption % = 100(Wb - Wd) / Wd

Where:
Wd = dry weight of the specimen.
Wb = saturated weight of the specimen after submersion in boiling water.

The saturation coefficient was estimated as follows after performing the two absorption tests:

Saturation coefficient = (Wc (24)-Wd) / (Wb (1) - Wd)

Where:
Wd = dry weight of the specimen.
Wc (24) = saturated weight of the specimen after 24 h submersion in cold water
Wb (1) = saturated weight of the specimen after 1 h submersion in boiling water.

The water absorption tests conducted on the two most promising types of bricks (HDPE/Sand – Household/Sand) show the effect of adding a binder, the difference absorptions between the types of bricks and finally the differences in the ratio with sand applied.

The experiments used were 24 hours of immersion and one hour of boiling. The first is used to assess the brick in a partially saturated state, while the second is intended to simulate a saturated state. The saturation criterion can be avoided if the cold water absorption for 24 hours does not exceed 8%, according to ASTM C62 rules. As a result, the 60% HDPE, 40% sand, and 10 g binder sample meets this criterion.

According to the DTU team, all of the samples fail to meet the ASTM C62 criteria for overall saturation, but individual moisture absorption numbers are acceptable. The compositions comprising household plastic absorb more water than the mixtures containing HDPE, as can be seen in the table (Figure 42). Furthermore, whereas the samples containing 5 g of binder showed no significant improvements, when the binder content is increased to 10 g, we see less absorption for both ratios. This is in line with the findings of the 1 hour boiling tests. The researchers noticed a lot of sand being flushed out of the bricks during the boiling process, which could explain why the hot absorption percentage is always lower than the cold absorption percentage. This resulted in a loss of mass, but by adding the binder, the mix is strengthened with fewer porosities, preventing the sand from being flushed out.

- Compressive Strength Test:

Composition	Ratio	Binder (g)	Dry weight (g)	Cold absorption %	Hot absorption %	Saturation coeff.
HDPE / Sand	60/40	5	480.8	13.64	11.13	1.23
		10	523.3	2.45	1.18	2.06
		0	522.66	12.01	8.54	1.53
	70/30	5	430.42	25.80	23.55	1.1
		10	445.08	9.6	6.79	1.41
		0	492.73	15.84	7.84	2.11
Household plastic / Sand	60/40	0	468.67	18.96	16.72	1.64
	70/30	0	370.53	32.68	20.19	1.73

Table 5: Water absorption test results.
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The samples were placed in the center of the piston and pressed with a pressing machine. When the tested bricks had been damaged enough, the tests were stopped. The samples' compressive strength is calculated as follows:

Compressive strength, C = W / A

Where:
C = compressive strength of the specimen, MPa
W = maximum load, N, indicated by the testing machine
A = average of the gross areas of the upper and lower bearing surfaces of the specimen, mm2.

The graph (Figure 37) displays a typical load curve for the samples. Due to the team stopping the testing machine before the fraction point for technical issues, there is no easily identifiable point of fracture, therefore the load could have kept increasing because the material could have probably supported it. Based on the findings, it appears that compositions containing a higher proportion of plastic have a higher sustained load. HDPE appears to be the strongest, exhibiting better mechanical properties compared to the household compositions. The individual strength of the bricks should be between 8.6 and 17.2 MPa when referring to the minimum compressive strength according to C62 specifications. All HDPE samples return an average of 10.75 MPa, putting them in this range. However, the performance of household compositions is not up to par.

The students at DTU were able to see the interior structure of the brick after destroying the samples after they were pressed by the machine. They determined that the brick had not fully melted, indicating that all tested bricks are likely identical. Because it behaves more like a mound of gravel than a bulk solid, this type of unmelted internal structure alters compressive strength. It is important to note that this problem will not be present in the case of using the same material for façade panels due to a much smaller internal volume.

- Workability:

The varying compositions, binder application, ratios, and heating procedures utilized to improve the product's quality, must be studied by comparison in order to understand their repercussions. The product's heterogenous appearance was a significant aspect in the evaluation. However, this variety resulted in differences of workability characteristics. The HDPE / Sand sample was the most rock-like, with small superficial cavities and good sand adhesion. The smoothest surface, with few to no voids, was found in the household plastics / sand combination. The density, on the other hand, was significantly lower than in the first sample. The PP / sand combination was difficult to fill the mold and easily deformed due to the excessive shrinkage of the PP material. The carbonized mix / sand combination was not practical because the plastic particles were too large to melt, and the heterogeneous mixture of wood and other miscellaneous components made it difficult to deal with and displayed a lot of cavities. These results render HDPE and household plastics to be the most promising options.

(Table 7) Thanks to the table we understand that height is the most unstable parameter in each type of brick compared. This is due to the mean of operating and fabricating the brick by hot embossing. Moreover, sand ratio affects the size stability, by comparing A (60% HDPE 40% sand) to B (70% HDPE 30% sand) and C (60% household plastics 40% sand) to D (70% household plastics 30% sand). As it appears, higher sand percentage leads to more stability in size.

Using sand as a filler brings its advantages and inconveniences. Sand increases density, surface roughness, hardness of a plastic product, lower flammability, and higher fire retardation. However, sand also reduces the fracture toughness and compressive strength of a material. These qualities, however, are very changeable depending on how well the sand is mixed into the plastic melt. Plastic has a lower resistance to UV light than clay, moreover plastic will naturally be more prone to creep.

Sample #	Brick composition	Compressive strength (MPa)
47	70/30 HDPE / Sand	15.28
29	60/40 HDPE/ Sand (after water absorption)	12.05
76	60/40 HDPE/ Sand+10g binder (after water absorption)	9.11
75	60/40 HDPE/ Sand+10g binder	6.55
46	70/30 Household plastic / Sand	2.94
40	60/40 Household plastic / Sand	2.18

Table 6: Compressive strength test results.
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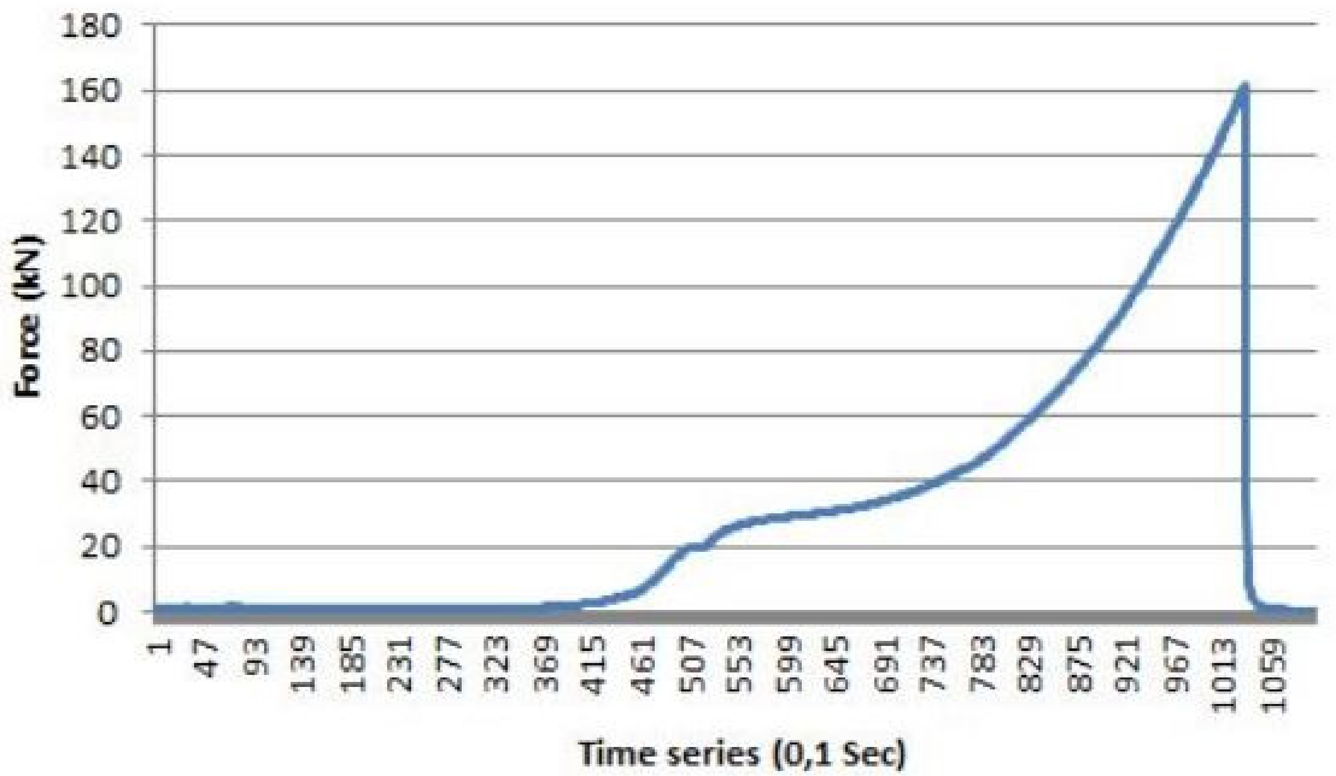

Figure 37: Compressive strength graph for sample #47 (Highest recorded compressive strength).
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Standard deviation	A (13)	B (13)	C (8)	D (5)	All (56)
Height	1.92	1.42	1.79	1.57	1.78
Width	1.11	0.53	1.15	0.15	0.99
Length	0.96	0.62	0.48	0.35	0.98

Table 7: Standard deviation in cm of the samples.
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On the other side of the world, in Michigan, USA, a group of architects/teachers called T+E+A+M investigated the application of plastiglomerate at different scales in the architectural field. The experience gained from this office helps us understand what comes into play when working with plastiglomerate as a building material. Their experience answers questions ranging from the market demand opportunities to the philosophical applications of plastiglomerate. T+E+A+M tend to call the material "Post Rock".

One of the architects at T+E+A+M called Thom Moran, lectured at UC Berkeley Architecture Environmental Design, part of the Arch 260. In this lecture, the architect journey's through their work at the office and explains their experiences relating to "Post Rock". (Miller, M., 2018).

Their architecture is a relationship to the environment done through experimentation, acknowledging the fact that plastiglomerate will not stop forming anytime soon. They argue that what is happening in the oceans right now, is just going to keep happening and that shores are going to end up with plastiglomerate whether we like it or not. So as architects, they decided, to figure out how to build with it, and assume that it's going to be some future natural resource. They've tried to reframe it as a natural resource, instead of the environmental disaster that it is.

They began to imagine what architecture could be like, built from this material. They wanted to experiment with this durable material, being made of plastic and inorganics like sand and rock. What they sought to do was to simulate the production of plastiglomerate in the lab in Michigan, and figure out how to make it, and then once they've made it, what could they do with it.

A common criticism to the process of imitating plastiglomerate in a lab, consists of making more of this material which is bad for the environment. However, the team's rebutal to that criticism is that it is already happening, and their method is to try to proactively figure out a way to be able to build with it, hence in the process, reuse waste.

Plastiglomerate presents itself generally with a chunk of rock, sand or a shell that is identifiable, even rope or chunks of lid. The aesthetics of it were also something they were drawn to and the notion that each piece of plastiglomerate registers where it came from.

Over the years, they've progressively scaled up and expanded the scope of their projects, making their own molds in different machines like roto molders and robotic technology.

The collection of different materials that would be put in a mold, heated, and rotated would get different versions of plastiglomerate out of the process. This led to an examination of the relationship between the inputs and the output. How much of the inputs get registered in the output. This relationship was important for the team because they are interested in the structural properties and material qualities of it, but also the visual qualities that tell a story about where it's from.

(Firgure 39) T+E+A+M has been working on two processes. The first one is to imitate the clastic process, which is the natural process of the materials that gets made churned around in the ocean, and the other one made in-situ, which happens just in one place on a beach due to campfires or just through UV radiation.

So, they have made their own versions of each, one (clastic) through rotating, almost in a rock tumbler, through heat and movement, and one (in situ) just by melting components together, statically. The results variated immensely. The repetition of this process, with results coming out differently at each take. They have learned a lot from hands-on prototyping, and understood how to make it and control the qualities of it.

(Figure 40) As a thought experiment they identified three different material ecologies: urban beach, agribusiness, and suburban domestic. These are all big sources of waste plastic.

On an urban beach you would have all the waste related to beach activities: the inorganic sources in sand and seashells, and the organic plastics.

Figure 38: In-situ and clastic natural processes of plastiglomerate formation.
©Kelly Jazvac.

Figure 39: In-situ and clastic iterations by Meredith Miller and Thom Moran.
© Meredith Miller and Thom Moran.

Agribusiness is a huge producer of plastics waste, everything from tarps and water barrels to the polymer twines and sheets of plastic and fuel containers and organics such as stone and limestone and perlite.

Then of course the suburban homes filled with plastic. Including everything from the laminate on our countertops to the insulation on the conductors in our electrical wiring to the plumbing.

They wanted to do a series of projects that looked at those material ecosystems and found a way to both formalize and materialize, but also visualize them in different ways. For each, they tried to find different form factors, by variating the molding processes, and the different material ecosystems.

(Figure 40) For the “Plastic Sunrise” project, they came up with an architectural formal proposal but also did material tests to see what the first hand, intimate relationship with the material surface would be like.

(Figure 40) “Erratics”, in geology means a piece of stone that ends up somewhere that it shouldn’t be mostly due to glaciation. Erratic also means something that moves unpredictably, and so they propose these kinds of unpredictable plastic formations that would have rounded bottoms, from a distance it would create this kind of stunning visual, but then up close it would reward inspection and get people to touch the surface of the material and interact with the plastic objects.

(Figure 40) The last one, “Summerhouse”, where they looked at gravity mold technique of casting all the plastic vinyl elements of a suburban home into these inverted cones that would produce a stage for performances. The idea was that the objects of our suburban life, such as dish drying rack, could blush into the surface and produce something ghostly, skeletal, blurring the distinction between the geological and the familiar.

Another project they have worked on, called “Detroit Reassembly Plant”, concentrated on the materiality and representation. They grabbed pieces found in the abandoned building, 3D Scanned them to carefully study their materiality. They looked for other kind of debris and local waste streams, and the waste plastics of the region. They started to combine the materials of the site in different ways, they included different types of plastics, rubble, and other materials they found on the site. In the design of the project, they tried out novel ideas about construction, by making models that simulate the construction system. This exercice helped them bridge their previous small scale projects with different ideas of how to use waste products to make buildings at a large scale. In its realizability as a building, they drew detailed sections, they tried to make renderings that represented the materiality by making prototypes, 3D scanning, and then bringing them into the computer to render them back out.

There would be a constant feedback loop between the prototypical construction model and the design, and the images made, going back and forth between construction drawing to the scale mockup of the model, 3D scan, back into the imagery they were making.

T+E+A+M was then asked to contribute part of their material exploration and fabrication to a show at the California College of the Arts (CCA) exhibition, they decided to make a column out of what they call "Post Rock". The project’s name is “Clastic Order”.

(Figure 41) Taking some ideas from the “Detroit Reassembly Plant”, but also some of the ideas driving post rock to do a full-scale test of it. In this project, building construction and demolition waste was used. Building construction and demolition is a huge generator of waste. This is a response to the big amount of plastic found in the building sector, because a lot of building materials are plastic and a lot of building construction waste like plastic packaging materials, temporary fencing, that get thrown away in the process of constructing a building.

Like previous projects they have made, they were looking at the material ecology as a collection of inorganics and polymer plastics. Everything from brick, fencing, PVC pipe, and broken glass, produced during construction. The column installation for the show at CCA, let them test out different ways to combine

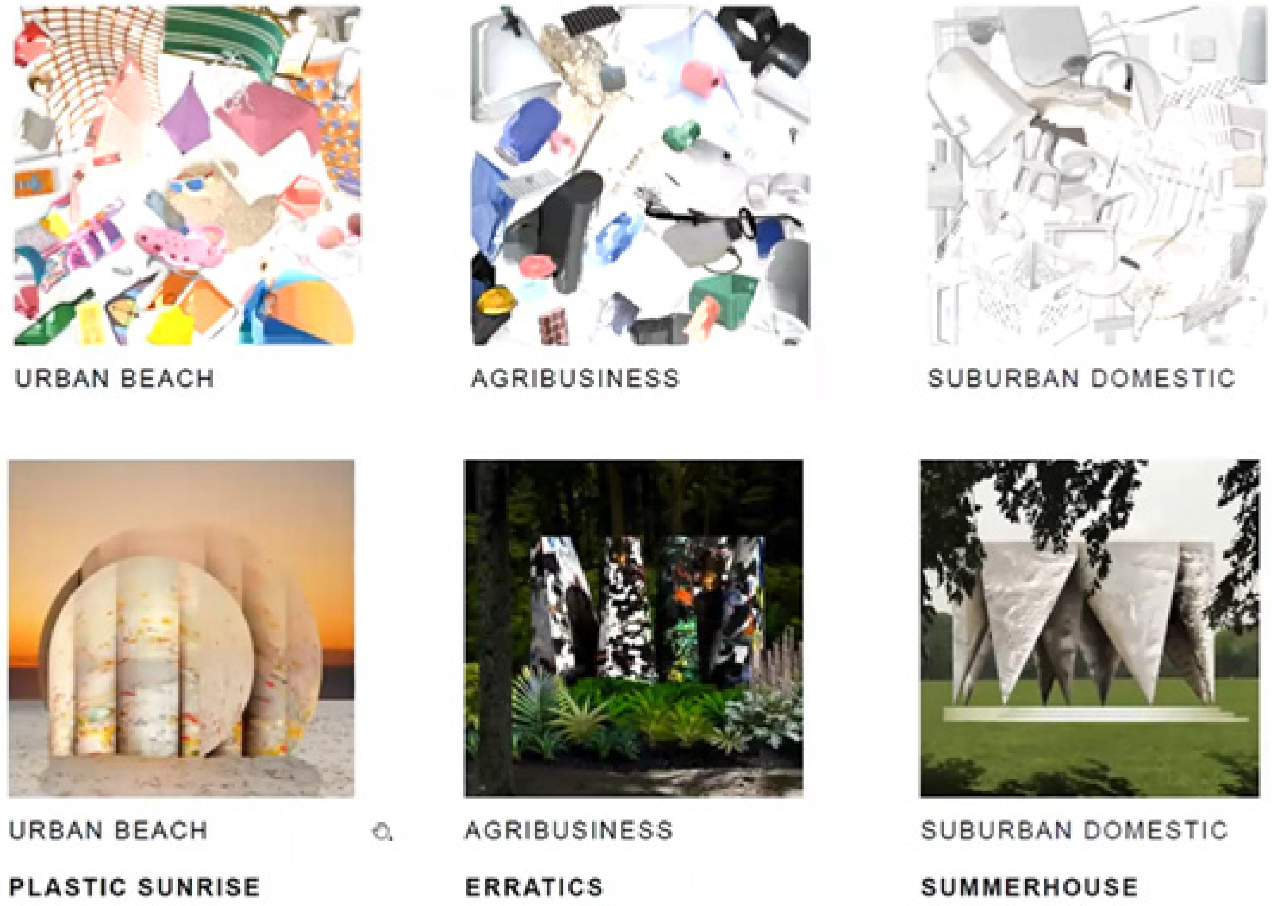

Figure 40: The three different materials ecologies experimented by Thom Moran and Meredith Miller.
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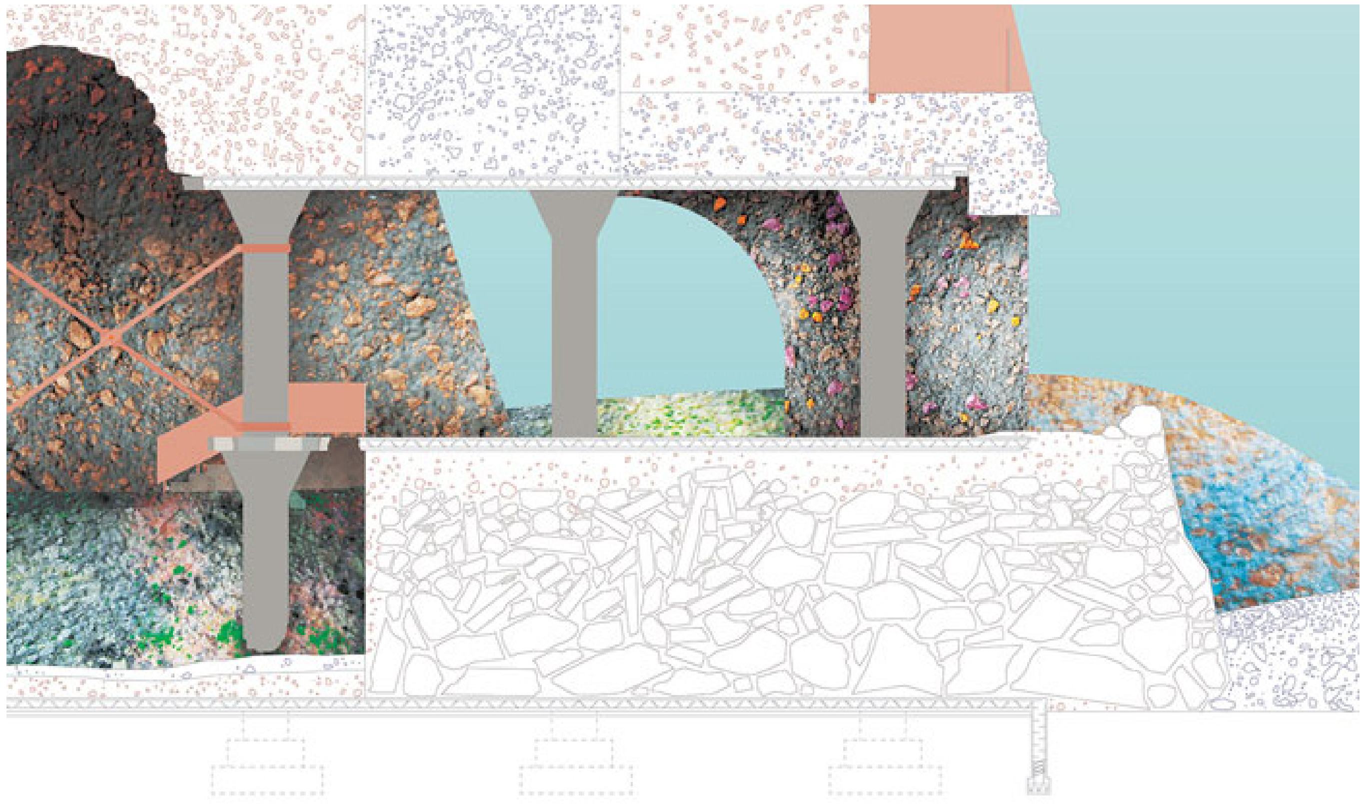


Figure 41: Detroit Reassembly Plant, detailed rendered section.
© T+E+A+M.

these materials. Committed to finding ways to reuse plastic as building material to get it out of the waste stream. However, this project is also conceptual and aesthetic. They weren't just interested in how to capture the most waste material and make that legible through the aesthetics of the project. A lot of testing different visual effects came into play along with figuring out the kind of techniques to cast an unconventional column like this.

(Figure 42) They tested two different ways, one is more akin to slip forming, the method used to build concrete elevator or stair cores or nuclear power plant cooling towers where you start a form at the bottom, you fill it with concrete, as that cures, you keep moving up one layer of formwork instead of having to build the whole format once. Due to the need to thermally cast plastic, by applying heat, thermo casting an entire column would an large amount of energy.

For aesthetic inquiries they tried two options. The first option, they heated the inside and left the outside raw, the second option, they heated the outside and left the inside raw. Respectively, the first, registers all the differences of the components and the other one homogenizes them. The particularity of the homogenized column mimics post-natural marble effect. Eventually, only one of the two columns succeeded structurally. However, both got exhibited to show that in the prototyping process and experimentation, there is trial and error. The homogenized column failed due to material expansion.

T+E+A+M went on an investigation to commercialize the product. A patent, or disclosure is needed when working on different material and fabrication technologies, with possible patentable intellectual property before making it public. Thence, the team asked themselves the following question.

What would it take for an experimental material to become a building product?

In order to answer to that question they applied what is called evidence-based entrepreneurship to fabrication research. It is a systematic approach to business development that emphasizes learning at the early stages, before substantial investment of time and resources. Information gathered from multiple sources is analyzed to challenge or verify business propositions. It entails, going out into the world and talk to people about what they need in their industry, about their experience and what could be missing without telling them what it is for. Discussing about the problems the prospective product could solve.

Following this systematic approach, they initially thought they were going to be manufacturing large scale building components or structural elements out of this composite material made of recycled materials and intervene on the construction and demolition waste material ecology, providing a low-cost product. Their previous projects went towards this initial idea such as "Detroit Reassembly Plant" and "Clastic Order".

As academic researchers, they thought it would be a straight line, from the initial idea to a desired built architectural project. However, it's more complicated to get an experimental material to a scale of a building.

They figured out by applying the evidence-based research that there is no shortage of products made of recycled materials. Meaning that the recycling aspect of the product that they wanted to propose was not going to be the value that makes it stand out. However, they noticed a shortage of heterogenous rainscreen products that provide a variation and simultaneously feel contemporary.

"The story behind the material and its uniqueness is more of a selling point than gaining LEED points; LEED is only an added benefit."

"With the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 2010, the energy standard for most buildings in North America, more firms are going to move to rainscreen products because there aren't really any other wall assembly materials that can be cost effective."

In contemporary architecture, a continuous insulating layer is applied, to meet the new

Figure 42: Clastic order installation column being molded using the slip forming method for the show at CCA.
© T+E+A+M.

Plastiglomerate as a Building Material

standards of building performance. Putting a rain screen over an insulation on the exterior of a vapor barrier, is an increasingly common and cost-effective way to do a building envelope even on lower-end budget projects. In the construction industry there is an increasing demand for rain screen products, but very few options to select from. (Alucobonds and fiber cements), so there's an expanding market for it.

This shifted their focus from designing monolithic structures or larger scale architectural components, to pursue a design for a rainscreen panel made of "Post Rock". (Figure 43) This synthetic material relates to our environment and embraces the potentials within construction. The architects see it as a net positive to find aesthetically exciting ways to capture materials from the waste stream.

However, the recyclability of the rainscreen itself is not possible because It is a composite material, and there are no means to dis-aggregate the polymers from the inorganics at that point. Nonetheless, T+E+A+M is researching for alternative solution to that problem by researching in the Design for disassembly thinking. Buntly, it means building is conceived by components that can be disassembled and reassembled in different ways. At this stage, this might be the only solution conceivable, and the results are satisfying enough because they are preventing waste to end up in the landfill.

As mentioned before, plastic as a material is designed with its tooling in mind, the material's limitation is that it must be prefabricated offsite. Hence, the strategies to employ are Design for Disassembly techniques of standardization and making sure the components are mechanically fastened, and not adhered, so it could be taken apart at some point. The standardization of heterogeneous materials, and its manufacturing properties stem two concerns.

The first one is to optimize the percentage of compounds that make up the resulting composite material. Their mixture dictates the structural qualities, surface qualities, aesthetics, and weight.

The second is to produce a uniform product out of heterogenous inputs. When you have a source of plastic that is more homogenous, it can be processed more consistently than in the case of using post-consumer plastics. When the source of the plastic is known, hence their properties aswell, a better understanding of the output can be expected. Usable and available, post-consumer plastics are good to use, however they are not the biggest source of plastic pollution, nonetheless, they are the most visible. The underlying waste is generated from post-commercial and post-industrial plastics.

This notion is sensitive to the context. Michigan in their case, relies on the industrial economy, and has big manufacturing companies specially in the automotive industry. These industries that use plastic are getting better at recycling their own plastics. Therefore, it is very important to understand in which context we are in order to build with this material.

"Post Rock" must be heavier than comparable materials commonly used for the same intended products to have the same kind of structural performance. However, the more plastiglomerate is used the more waste is being removed from the waste streams.

Plastiglomerate communicates about its formation, the place that it came from and its circumstances. It is important that at some level of inspection, the material transmits something to the viewer, it becomes a media. Material as a medium.

These two contributions analyzed help to understand the multiplicity of the interprative nature it has. Its flexibility to be used in broad and various ways, manufactored according to the purpose it is going to fulfill. With constants that give the material its identity, such as its heterogeneity, aesthetics, and its components' source-recording qualities. On a performative level, when created in a lab, it is easier to work with, and control. Its mechanical properties can hence be assessed. The sand and binder mixed with the plastic type of choice, renders it acceptable by ATSM regulations when managed correctly.

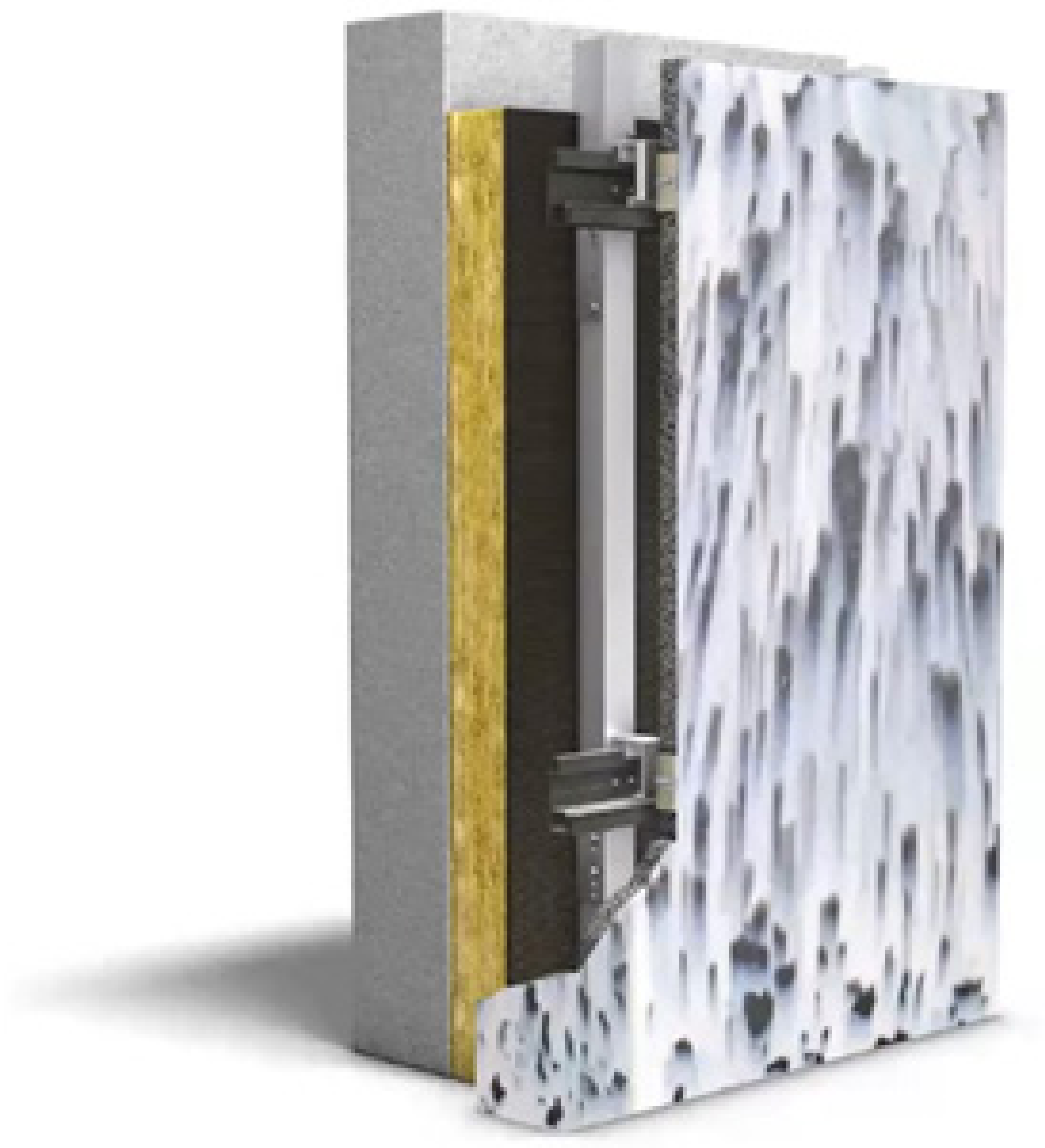


Figure 43: Rendered detail view of rainscreen made of Post rock' proposed by T+E+A+M.
© Lecture at UC Berkley, presentation slide.

5.5 Designing a Plastiglomerate Facade Panel

The designers combine all their findings into a design phase in the final stage of the MDD method. Designers may already have the product in mind, therefore material and product considerations go hand in hand in such circumstances. The designers now begin to create material concepts based on the research of the previous step as well as their understanding of the material studied in the first step. Mechanical testing in multiple iterations are used to assess the performance of the most promising concepts, while interviews and focus group studies are used to assess the material experience qualities. (Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A., 2015)

In our scenario, plastiglomerate presents itself as a semi-developed material in the field of architecture. Therefore, according to the MDD method the designer sustains the essence of the material's idea, but manipulates the components of the composite material to find alternative combinations, in our case it might be its contextuality. The designer proposes a certain combination of components and assesses their qualitative performance as a whole, keeping in mind the desired aesthetic qualities.

5.5.1 Deductions

As understood from the lecture given by the architect at T+E+A+M, plastiglomerate is not recyclable, yet it can be reused, if managed properly. Design for disassembly could be a way to mitigate that problem. It is a principle that is applied in the details of the fixtures. It indirectly criticizes the way the buildings are designed today, thinking that they will never be demolished. It calls for the architects to conceive in layers that are reversible and accessible. Furthermore, buildings would be easier and more economical to maintain and would result in the reduction of waste at the end of service life. Buildings would then literally serve as material banks.

The necessity to retrofit energetically existing buildings has increased in line with the requirements for thermal efficiency of buildings and building envelopes. This has come with ventilated facade systems providing one of the most appealing solutions for these indicated needs. Moreover, this system presents a multitude of liberty of choice in its aesthetic appeal, control over moisture, noise insulation, fire resistance, serviceability, resistance to climatic conditions, and disassembly opportunities. (Theodosiou, T., Tsikaloudaki, K., Bikas, D., 2017)

For ventilated facades to be disassembled it would translate to panels being mechanically fixed and detachable, to possibly reconfigure them according to new demands of function, or they could even be reused for other projects.

Retrofitting existing buildings is a major topic in the european context, more than 40 % of buildings are built before the 1960s. (Economidou, M. et al, 2011) Requirements for energy efficiency were absent back then, consequently these buildings nowadays considerably contribute to the building sector's excessive energy consumption. In this regard, there is great potential to improve in that area, hence, it is where much of the efforts for energy efficiency should be focused.

Which is why this thesis investigates using plastiglomerate as a building material for a rainscreen in a ventilated facade system applied on an existing building in Turin. Therefore, it is important to understand the different aspects that affect this proposition. Firstly, the ventilated facade system has to be defined in order to know where would the plastiglomerate contribute in it, and a quick look into the requirements for ventilated facade systems will be studied according to the UNI 8979 standard. Secondly, an inquiry into the standard of rainscreen properties will be deduced. Thirdly, plastiglomerate's choice of material components in Turin's context will be discussed.

5.5.2 Ventilated Facade System

Ventilated façade systems integrate the insulation layer, placed on the outer surface of the wall, behind the air gap and the rainscreen. Water that penetrates the cavity is flushed away through the air gap. A support system intended to carry both the weight of the system and the expected wind and earthquake loading is installed to secure the cladding. The support system is often made up of fastening rails that are bracketed to the structure.

A limitation of the system is the added structural weight on the existing façade, particularly in case heavier cladding material, such as concrete panels or natural stone, is applied. Moreover, depending again on the cladding material and the fixing system, the construction cost can be significant. The benefits of the system have to be balanced against its feasibility and expense, according to each project's design and ambition. (Bikas, D., Tsikaloudaki, K., Kontoleon, K., Giarma, C., Tsoka, S., & Tsirigoti, D., 2017, p.149)

Ventilated facade systems include the three main layers defined under the UNI 8979 Italian standard, in an interconnected way, the outermost layer functions as the external coating layer (first layer), which is supported by the connecting layer (second layer) and finally fixed via brackets to the main support layer (third layer). Plastiglomerate rainscreens are concerned by the first layer which is the external coating layer, it refers to the features of appearance and finishing. Aside the three main layers mentioned above, other layers are considered as functional layers, they can be seen as attributes to the three main ones. (Donsante, I., Tucci, F. 2020)

They include the thermal insulation layer, watertight layer, airtight layer to prevent wind pressure, sealed layer to keep out vapour, fire resistance layer, thermal accumulation layer to adjust the temperature, ventilation layer to provide for an upward air movement, coating layer, and regularisation layer.

Arbizzani (2021) states the following,
- Load distribution / stiffening layer: Its function is to distribute any concentrated loads on the coating layer, mainly due to accidental impacts, in the presence of yielding stratifications. The technical solutions are often integrated with the protection and coating layers through the insertion of reinforcement elements consisting of metal or fiberglass meshes in the functional models of the external or internal cladding wall.

- Support layer: It resists loads due to its own weight and those of the layers or elements connected to it, overloads due to wind pressure on the entire closing system and loads due to accidental impacts that can occur inside or outside the wall. Most of the functions of the other layers are very often identified in it. When it is layered, it can be made of reinforced concrete cast on site or with prefabricated panels and brick, cement or natural stone masonry. In this case the layers can be more than one. When it is conformed with technical elements it can be realized through linear structures or framed in wood, steel, aluminum.

- Thermal insulation layer: Its function is to bring the global thermal transmittance of the closure to the required value, according to the thermo-hygrometric conditions of the established building well-being needs. The sequence and location of this layer within the stratifications making up the wall significantly modify the behavior of the system in relation to thermal inertia problems. Its adoption also requires particular design criteria aimed at eliminating, in any case minimizing, the discontinuities deriving from the presence of structural elements inside the wall, which could generate specific phenomena of thermal dispersion (thermal bridges).

It can be placed on the internal or external surface of the structural element; or it can be placed in the cavity that is formed between two faces that split the resistant layer. When the thermal insulation layer is located on the external face it is usually coupled with a vapor barrier layer (placed on the internal face of the insulation), or it is placed before the ventilation layer. When the thermal insulation is located on the internal face it is covered with a protective and finishing layer (plaster or prefabricated layer).

The layer is generally made with materials characterized by low thermal conductivity, expanded in sheets or foamed, fibrous materials in rolls and sheets.

In building renovations, the insulating layer, traditionally made with a simple air chamber, or with insulating materials that have lost consistency and effectiveness over time, can be restored and improved through the blowing technique of insulating materials inside the original cavity.

- Sound insulation layer: The level of soundproofing required in buildings is always increasing, to the point that sometimes it is necessary to set up acoustic barriers placed for external protection, to reduce noise before it reaches the building and improve the acoustic climate of the surrounding environment. The functional layer of the vertical perimeter walls attenuates the flow of noise propagated by air or by impact; it is made up of high-density layers (which break down low frequencies), such as lead or concrete, and of elastic materials (which absorb high frequencies) made up of membranes or synthetic gaskets.

Where no particular acoustic insulation performance is required, the function is performed by the set of stratifications making up the functional model.

- Watertight layer: It has the function of giving the closure a level of impermeability to rainwater, resisting physical, mechanical, chemical stresses induced by the external environment or by use. Unlike roofing systems, in which the sealing layer is well characterized technologically in the form of waterproof sheets or layers, or through discontinuous sealing elements (bent tiles, tiles, etc.), in a vertical closing system the sealing function is generally absorbed by the combination of several layers, although not individually waterproof, which act by gradually retaining in their thickness the humidity that comes from the outside. In the case of walls with an external sealing layer, this coincides with the protection layer, giving surface waterproofing characteristics to the wall.

- Airtight layer: The layer has the function of giving the closure a level of air tightness and wind pressure. It takes on greater importance in light or transparent perimeter walls, due to the delicacy of the junction devices between the different elements. In wall partition systems it is achieved through additional regularization stratifications, while in prefabricated technical solutions the air tightness is obtained through sealing elements or paste sealing.

- Vapor barrier layer: It is adopted to avoid the accumulation of steam inside the system in the presence of thermal insulating elements, three circumstances occur:

- the heat-insulating element is protected on the outside by vapor-impermeable layers that prevent its migration from the internal environment to the external environment.
- there is significant humidity produced inside the building, in an external environment characterized by strong thermal changes and high relative humidity.
- the insulating element is made of a material sensitive to humidity, which in the presence of contact water would deteriorate.

In the sequence of the layers, the vapor barrier is always placed inside the heat-insulating layer, to protect it: if the main trend of the heat and humidity flow occurs from the inside-out and therefore it is necessary to prevent that on the external surface of the thermal insulation layer, where the thermal shock occurs, hence condensation of moisture into water occurs.

As for the insulation layer, a condition of continuity must also be ensured for the vapor barrier, otherwise there is the risk of triggering punctual situations of accumulation and interstitial condensation. In current production, in general, the product is already coupled to the component materials of the thermal insulation layer, in the form of a film or polymer-based sheets.

- Vapor diffusion layer: This layer is also necessary in the presence of particularly humid environments but, unlike the barrier, it allows the passage of humidity, however slowing its flow, consequently decreasing its pressure and spreading it over a larger surface. Its behavior is useful to allow the transpiration of the wall.

- Protective layer and coating: It is placed both on the external and internal surface of the perimeter wall. On the outside it assumes a protective function from atmospheric agents and a decorative function, while on the inside it constitutes the surface that resists the punctual loads and the functional and tactile aesthetic needs expressed by the occupants.

The external appearance of the facade surface depends on it. The relative design choices also focus mainly on the aspects of durability in relation to the phenomena of degradation induced by surface washout, sunshine, as well as the action of frost and wind. The choice of materials and installation systems depend on the degree of aggressiveness of external agents.

The external layer of a facade is designed for a certain life cycle, beyond which it must be restored or replaced so that it can continue to perform its protective function; for this reason the coating layer is also referred to as the “sacrifice layer”. The technical solutions differ in relation to the type of underlying support and range from the different mixes of traditional plasters to increasingly advanced materials, such as synthetic films and metal laminates, cement-based, plastic.

- Fire protection layer: It is a fireproof barrier designed to protect technical elements that do not possess the necessary characteristics of resistance and reaction to fire, made with inert materials such as foams or intumescent paints or with panels, in fiber cement, calcium silicate or plasterboard. In the interconnections between different technical elements, timely protection may be necessary to avoid the spread of fire between one room and the other above.

- Connecting layer: A connection layer is defined as any device, element or integrated set of elements having the function of ensuring the connection of an element carried to the support layer. It has the function of creating a stable bond between the coating layer and the surface of the underlying support layer or of any leveling and sealing layer.

It differs considerably in thickness and material used, both in relation to the type and surface conditions of the support, and in relation to the characteristics of the coating adopted. It can be continuous or discontinuous in relation to the application methods and the possible need to create a layer of micro-ventilation between the support and the coating, or to create a condition of continuity for the transfer of tensions present in the coating to the more rigid support layer.

The technical solutions refer to the type of adhesive stratifications or to that of mechanical devices.

- Regularization layer: It has the function of reducing the surface irregularities of the underlying layer, due to anomalies caused by mechanical stresses in the adjacent layer, it is also used to improve the adhesion between two layers contiguous.

It can be made up of cementitious skim coats or gypsum-based layers that ensure the flatness and at the same time the roughness of the surface, necessary for better anchoring of other layers. In other cases, the regularization action can also be performed by adjusting mechanical fastening devices for metal frames used to support the protection and / or coating layers.

- Ventilation layer: It has the function of contributing to the control of the thermohygrometric characteristics of the closure through the exchange of air, either naturally or forced. Its operation gives rise to the functional model of the ventilated wall. With it, in fact, in the cold season it is possible to dispose of the steam coming from the internal environments or the humidity coming from the outside, and in the hot season to reduce, through convective motions, the quantities of heat due to solar radiation that hit the wall, reducing inward radiative exchanges.

The layer, essentially consisting of a cavity inside the wall system (40-100 mm), can give differentiated performance responses according to the different levels of activation of the ventilation: for this purpose it must allow the introduction of air into the bottom of the cavity and its expulsion at the top. For correct operation, the external protection layer must be formed by an almost continuous surface: discontinuities are allowed, given for example by the joints between sheets, of such dimensions as not to allow the creation of significant air leaks.

Some technical solutions provide for minimum air chamber stratifications (10-20 mm) to allow micro-ventilation for the sole purpose of dehumidification.

In addition to the technical requirements, legal, social and financial variables should be considered.

5.5.3 Rainscreen Standard Properties

The suggested plastiglomerate rainscreen product, attributes to the external coating layer in the UNI 8979 Italian standard. As seen above, this layer of the envelope is assigned to functional properties it should verify in order to perform well and contribute to the durability and energy efficiency of the building. It is indeed the building's protective layer, otherwise called the "sacrifice layer", since it is at the forefront of any exterior factor. It should endure climatic, sound, radiation, chemical, fire and physical factors, all exposing it to degradation risks.

Regarding the thermal insulation, the rainscreen layer has to successfully cover the thermal insulation from humidity and water, therefore the panel itself should be watertight and the distances between the panels should be restricted to a minimum. This contribution of the rainscreen as part of a whole system, also follows the same logic for several other functional layers such as: watertight layer, airtight layer, vapor diffusion layer, and ventilation layer.

In relation to the sound insulation, the rainscreen layer would also be contributing as part of the whole that makes up the stratified system. In that sense, the stratification of layers functions as successive weakening of external sounds.

The fire resistance layer, has to be successfully achieved by ensuring good burning behaviour, diminishing gases and smokes, this is done by the right selection of the material composing the external layer.

The solidity of the material itself would also contribute to the durability of the plastiglomerate, protecting it from environmental agents, preventing penetration of various factors into the material affecting it physically or chemically as seen in (3.1 - Plastics Building Material Properties).

In relation to the connecting layer, it has to ensure precise vertical flatness, the alignment can prevent exposure to wind, and water. In our case, with the design for disassembly process, the fasteners would have to be mechanical fixed.

The ventilation layer will be ensured by keeping a distance with the other layers behind (40 to 100 mm), this cavity would provide an upward movement of ventilation, regulating the temperature and good circulation of air, also assisting against defective humidity. However, good ventilation is attained by minimizing air leaks between the panels of the external protective layer (rainscreen), nonetheless gaps are allowed but with restricted distances as to ensure enough space for thermal dialation.

Lastly, the aesthetic appearance of the rainscreen is of special importance for the application intended. Plastiglomerate should be identified in the final product, engage and be seen by the users.

In order to assess the plastiglomerate rainscreen proposed, we consider the standard according to EN 438-6 of decorative high-pressure compact laminates, a product named Meteon by Trespa. The similarities in function would permit us to determine the expected properties of our product. However, it is to be noted that the compared non-porous product consists of layers of wood-based fibres impregnated with thermosetting resins, with a transparent topcoat for weather and light protection.

Amongst the properties shown in (Table 8), taken from (TRESPA, n.d.) we can incorporate the following:

- Similar surface quality standards are to be applied.
- Dimensional tolerances are to be respected with the exceptions of the thickness and flatness which have to be more tolerant in the case of plastiglomerate due to the nature of the material and its intended imperfections for experiential purposes.
- Physical properties, weather resistance properties and fire performance are to be maintained.
- A lower thermal resistance/conductivity can be tolerated, for a rainscreen application.

However, the performance requirements listed in (Table 8) have to be achieved by testing and identifying the appropriate additives to be applied on the chosen plastic.

Properties	Test method	Property or attribute	Unit	Result A B Grade: EDS (Meteon®) Standard: EN 438-6 Colour/Decor: All B	Grade: EDF (Meteon® FR) Standard: EN 438-6 Colour/Decor: All B
Surface quality					
Surface quality	EN 438-2 : 4	Spots, dirt, similar surface defects	mm²/m²	≤ 2	
			in²/ft²	≤ 0.0003	
		Fibres, hairs & scratches	mm/m²	≤ 20	
			in/ft²	≤ 0.073	
Dimensional tolerances					
Dimensional tolerances	EN 438-2 : 5	Thickness	mm	6.0 ≤ t < 8.0: +/- 0.40	
				8.0 ≤ t < 12.0: +/- 0.50	
				12.0 ≤ t < 16.0: +/- 0.60	
			in	0.2362 ≤ t < 0.3150: +/- 0.0157	
				0.3150 ≤ t < 0.4724: +/- 0.0197	
				0.4724 ≤ t < 0.6299: +/- 0.0236	
	EN 438-2 : 9	Flatness	mm/m	≤ 2	
			in/ft	≤ 0.024	
	EN 438-2 : 6	Length & width	mm	+ 5 / - 0	
			in	+ 0.1968 / - 0	
	EN 438-2 : 7	Straightness of edges	mm/m	≤ 1	
			in/ft	≤ 0.012	
	Trespa Standard	Squareness	mm	2550 x 1860 = max. difference between diagonals (x-y) = 4	
				3050 x 1530 = max. difference between diagonals (x-y) = 4	
				3650 x 1860 = max. difference between diagonals (x-y) = 5	
				4270 x 2130 = max. difference between diagonals (x-y) = 6	
			in	100.39 x 73.23 = max. difference between diagonals (x-y) = 0.1575	
				120.08 x 60.24 = max. difference between diagonals (x-y) = 0.1575	
				143.70 x 73.23 = max. difference between diagonals (x-y) = 0.1969	
				168.11 x 83.86 = max. difference between diagonals (x-y) = 0.2362	
		Curved Elements C	Radius inside/ outside corner mm	n.a.	970/980 +/- 5%
					1290/1300 +/- 5%
			Radius inside/ outside corner in		38.19 / 38.58 +/- 5%
					50.79 / 51.18 +/- 5%
			Max. height mm	n.a.	r 970 / 980: 1300 (-0/+5)
					r 1290 / 1300: 1300 (-0/+5)
			Max. height in		r 38.19 / 38.58: 51.18 (-0/+5)
					r 50.79 / 51.18: 51.18 (-0/+5)
			Max. angle (°)	n.a.	90 +/- 0.5°
Physical properties					
Resistance to impact by large diameter ball	EN 438-2 : 21	Indentation diameter - 6 ≤ t mm with drop height 1.8 m	mm	≤ 10	
Impact resistance	ASTM D5420-04	Mean failure height	ft	1.0466	
		Mean failure energy	J	11.3	
Dimensional stability at elevated temperature	EN 438-2 : 17	Cumulative dimensional change	Longitudinal %	≤ 0.25	
			Transversal %	≤ 0.25	
Resistance to wet conditions	EN 438-2 : 15	Mass increase	%	≤ 3	
		Appearance	Rating	≥ 4	
	ASTM D2247-02	Water resistance	Rating	No change	
	ASTM D2842-06	Water absorption	%	0.5	
Modulus of elasticity	EN ISO 178	Stress	MPa	≥ 9000	
					Curved Elements: ≥ 8000
	ASTM D638-08	Stress	psi	≥ 1305000	
Flexural strength	EN ISO 178	Stress	MPa	≥ 120	
	ASTM D790-07	Stress	psi	≥ 17500	
Tensile strength	EN ISO 527-2	Stress	MPa	≥ 70	
	ASTM D638-08	Stress	psi	≥ 10150	
Density	EN ISO 1183	Density	g/cm³	≥ 1.35	
	ASTM D792-08	Density	g/cm³	≥ 1.35	
Resistance to fixings	ISO 13894-1	Pull out strength	N	6 mm: ≥ 2000	
				8 mm: ≥ 3000	
				≥ 10 mm: ≥ 4000	
				0.2362 in: ≥ 2000	
				0.3150 in: ≥ 3000	
				≥ 0.3937 in: ≥ 4000	
Other properties					
Thermal resistance / conductivity	EN 12524	Thermal resistance / conductivity	W/mK	0.3	
Weather resistance properties					
Resistance to climatic shock	EN 438-2 : 19	Flexural strength index (Ds)	Index	≥ 0.95	
		Flexural modulus index (Dm)	Index	≥ 0.95	
		Appearance	Rating	≥ 4	
Resistance to artificial weathering (incl. Light fastness) *West European cycle*	EN 438-2 : 29	Contrast	Grey scale ISO 105 A02	4-5 E	
		Contrast	Grey scale ISO 105 A03	4-5	
		Appearance	Rating	≥ 4	
Resistance to artificial weathering (incl. Light fastness) D *Florida cycle 3000hrs*	Trespa Standard	Contrast	Grey scale ISO 105 A02	4-5 E	
		Contrast	Grey scale ISO 105 A03	4-5	
		Appearance	Rating	≥ 4	
Resistance to SO_2	DIN 50018	Contrast	Grey scale ISO 105 A02	4-5 E	
		Contrast	Grey scale ISO 105 A03	4-5	
		Appearance	Rating	≥ 4	
Fire performance					
Europe					
Reaction to Fire	EN 438-7	Classification t ≥ 6 mm / 0.2362 in	Euroclass	D-s2, d0	B-s2, d0
		Classification t ≥ 8 mm / 0.3150 in (Metal Frame)	Euroclass		B-s1, d0
Reaction to Fire (Germany)	DIN 4102-1	Classification	Class	B2	B1
Reaction to Fire (France)	NF P 92-501	Classification	Class	M3	M1
North America					
Material Surface Burning Characteristics F	ASTM E84/UL 723	Classification	Class	n.a.	A
		Flame Spread Index	FSI	n.a.	0-25
		Smoke Developed Index	SDI	n.a.	0-450
Asia Pacific					
Reaction to Fire (China)	GB 8624	Classification	Class	D-s2, d0	B-s1, d0, t1

Table 8: Meteon by Trespa, material properties of the decorative high-pressure compact laminates.

5.5.4 Plastiglomerate Rainscreen in Turin

As we have understood after an extensive research on the use of plastiglomerate in the architectural field, this composite material should tell a story of its origin. The components its made of constitute its qualities to be used as an appealing tool to engage with the citizens. It is the feature it holds up when compared to other rainscreen products found in the market.

Hence, the materials sourced for producing plastiglomerate are of upmost importance to the intended output. The materials used should be from the local discarded waste, bounding it to its context. Rendering it emanating a regional criticality about waste that demands for anthropogenic consciousness.

Therefore, with the previous experiences with plastiglomerate for building purposes, notably by artist Veronika Geiger and the students at DTU, the lab-fabricated plastiglomerate for brick use is reduced to three components;

1. HDPE plastic (Aggregate / Binder)
2. Sand (Aggregate)
3. Sodium silicate (Binder)

This combination has proved to be successful with a certain ratio of sand/plastic and a certain amount of binder. The results have turned out to be satisfactory both for its mechanical properties and aesthetic appearance.

This was achieved by applying sodium silicate as a binding agent, which hardened the product by cohesion with sand; it prevented it to flush out. The selection of the binder was carefully thought to not hinder the final appearance of the brick, due to it being transparent. On the water absorption test, at 10 g of added binder to the mix, the absorption was within the attributed standards (ASTM C62) at lower than 8%. Furthermore, sodium silicate advantageously does not need heating to cure because it can be done at room temperature, rendering it a sustainable option.

An optimal ratio of 60% of plastic and 40% sand, according to the tests they have conducted, through experimentation with different material ratios.

A good choice of the plastic type HDPE, which is light with a high tensile strength and density of 0.93 to 0.97 g/cm3. HDPE is relatively hard and resistant to impact compared to the other plastics compared and can be subjected to temperatures of up to 120 C without being affected by it, which is within the required properties according to the table above (Figure x). Furthermore HDPE is a resistant material to many chemicals. It is normally used for domestic purposes, thus it removes the risks of toxicity. It also presents good adhesion to sand. (Chang, X. et al 2018)

Sand as opposed to some larger aggregates found in natural plastiglomerate, presents higher density properties, homogeneity, adds better UV resistance, higher fire-retardation, lower flammability, hardness, and helps with the size stability. (Chang, X. et al 2018)

However, these materials have fallbacks and should therefore not be overlooked, HDPE has a low UV resistance, moreover, it needs pressure to be applied in order to be coherent to the other components. Sand, can have the potential to lower fracture toughness and compressive strength, both of which can be highly variable, according to how incorporated the sand is in the plastic melt. In addition, a plastic brick will potentially be less UV resistant in comparison to a clay brick, and the plastic will naturally be more prone to creep. (Chang, X. et al 2018)

For lack of time, this thesis will have to deduce from the information provided. The materials to be used for the plastiglomerate rainscreen product. Therefore, further investigation through materials experimentation with the proposed combination would have to be tested in the lab.

Seeing that the proposed plastiglomerate rainscreen is in Turin, the materials constituting the final heterogenous product would have to be supplied locally. Therefore, the chosen materials will be related to the availability in Turin's context.
Firstly, the rainscreen product should include only one type of plastic, due to differences of properties between the types. As we have seen in chapter four, the un-recycled fraction of plastic packaging presents a variety of types of plastic to choose from. However, the most abundant type estimated turned out to be PE which includes HDPE. Therefore, in reliance to successful previous experimentations with this type, it will be chosen for its abundance and performance properties. The plastic will constitute 60% of the mix. The HDPE used for the rainscreen in Turin will be supplied by Demap the sorting center at Beinasco. Its proximity would reduce transportation costs and CO_2 consumption.

With PE encompassing four common types classified by density and branching. The amount estimated of un-recycled polyethylene in Turin (according to chapter 4 = 8588 t) would have to be divided.

The common types of PE include:
- Low-density polyethylene (LDPE)
- Linear low-density polyethylene (LLDPE)
- High-density polyethylene (HDPE)
- Medium-density polyethylene (MDPE)

LDPE and LLDPE constitute 17.4% of all plastic demands in all fields in Europe. They are used for reusable bags, trays and containers, agricultural film, food packaging film, etc.
HDPE and MDPE constitute 12.9% of all plastic demands in all fields in Europe. They are used for toys, milk bottles, shampoo bottles, pipes, houseware, etc. (Plasticseurope, 2021)

With these percentages we can therefore, roughly estimate that 42.6% of PE are either HDPE or MDPE. For lack of information, we assume that this share is split in half. As a result, 21.3% of 8588 tonnes would be un-recycled HDPE. (1829 t)

If we consider panels with dimensions of 600 mm x 1500 mm x 12 mm with HDPE's density of on average 950 kg/m^3, at 60% ratio in regards to sand.

w= 0.6 m x 1.5 m x 0.012 m x 950 kg/m^3 x 60% = 6.16 kg / panel

With 1829 t (1829000 kg) of HDPE we could produce 296915 panels.

Secondly, as a substitute to sand, fine recycled aggregates will be used due to it being C&DW that is the least recycled. Fine recycled aggregates are an opportunity to be considered for rainscreen products, due to reduced demands for compressive strength compared to uses in structural concrete. The fine aggregates will constitute 40% of the mix.

In Italy, extensive limestone usage will be translated in the composition of the fine aggregates, and in their properties. Their approvision would not be an issue, even if in Italy's context not a lot of buildings are being constructed or demolished. The few cases are enough to supply for a commercialized plastiglomerate rainscreen, because the 46.31 million tonnes per year of C&DW iare rarely reused in new constructions in Italy. (Junak, J., Sicakova, A., 2017) Moreover, it would also be interesting to study the construction waste of big infrastuctural projects, such as the on-going tunnel linking Turin to Lyon.

If we consider panels with dimensions of 600 mm x 1500 mm x 12 mm with fine recycled aggrigates's (FRA) density of on average 2300 kg/m^3, at 40% ratio in regards to HDPE.

w= 0.6 m x 1.5 m x 0.012 m x 2300 kg/m^3 x 40% = 9.94 kg / panel

Lastly, the binding agent to be used would have to be sodium silicate, for its conforming properties relating to the desired final product appearance. As Chang, X. et al (2018) state, the working principle of the sodium silicate (water glass) binder is that it slowly reacts to CO_2 through mixture, however, there is no need to apply heat for it to adhere and have cohesive properties due to its curing properties at room temperature. Sodium silicate reacts with the hydration products of Portland cement and not commonly used natural sand, hence the binder will likely adhere to FRA.

Subsequently, it is clear that there is enough supply to commercialize the plastiglomerate panels with HDPE, FRA, and sodium silicate, and that this combination allows for a functioning, cohesive, and durable product. When molded together to form a rainscreen panel shape, they could be applied to cover new buildings and/or retrofit existing ones.

Properties / Materials	HDPE	Fine Recyled Aggregates	Sodium Silicate
Chemical resistance	HDPE is a low-polarity polymer, which is why its chemically resistant. Indeed, the higher the polarity of the solvent and the polymer, the stronger the interactions between them.	Higher sulfate resistance Lower chloride resistance Higher carbonation	Stable in neutral and alkaline solutions
Electrical	Arc Resistance: 100 - 180 sec Dielectric Constant: 2.3 Volume Resistivity x 10^{15}: 16 - 18 Ohm.cm Dielectric Strength: 17 - 24 kV/mm Dissipation Factor x 10^{-4}: 3 - 20	NA	NA
Mechanical	Strength at Break (Tensile): 25 - 45 MPa Strength at Yield (Tensile): 25 - 30 MPa Young's Modulus: 0.5 - 1.1GPa Flexural Modulus: 0.75 - 1.575 Gpa	Decreases split tensile strenght Decreases modulus of elasticity Decreases compressive strenght Decreases Abrasion	Cohesive strength Stiffening properties
Physical	Density: 0.94 - 0.97 g/cm3 Gamma Radiation Resistance: Fair Glass Transition Temperature: -110 °C Shrinkage: 1.5% - 4% UV Light Resistance: Poor Water Absorption 24 hours: 0.005%- 0.01%	Density: 1.89 - 2.7 g/cm3 (Less dens than fine natural aggregates) UV Light Resistance: Fair Water Absorption 24 hours: 4.3% - 13.1% (Higher water absorption than natural fine aggregates) Improved frost resistance	Density: 1.37 g/mL Molecular weight: 140.08 Appearance: Colorless liquid pH: 11-12.5 (20 °C) Melting point: 0 °C Boiling point: 100 °C
Thermal	Coefficient of Linear Thermal Expansion x 10^{-5}/°C: 6 - 11 Thermal Insulation: 0.45 - 0.5 W/m.K Fire Resistance (LOI): 17 - 18 Flammability, UL94: HB	Fire Resistance (LOI): 9 - 23	Can withstand temperatures up to 1100 °C

Table 9: Proposed materials' properties.
© Fine Recycled Aggregates information: Nedeljković, M., Visser, J., ŠAvija, B., Valcke, S., & Schlangen, E. (2021) / HDPE plastic information: Omnexus SpecialChem / Sodium Silicate information: American Elements. [Compiled by Thierry Ramia]

6. Envelope Application on an Existing Building in Turin

Figure 44: Torre Littoria's air raid siren durin World War II.
© Archivio Storico della Città.

6.1 Building Choice: Torre Littoria

- Strategic Location:

The building of choice should be one that is easily seen (High-Rise, in front of Piazza Castello), so that the plastiglomerate rainscreen engagement with the people could have more effect and communicate to the larger population. Strategically located in that sense, the Piazza Castella being a static place would serve as an observation point.

Torre Littoria is the first high-rise residential building in the city of Turin, as well as one of Italy's best-known rationalist buildings. It is located in the city center, in via Giovanni Battista Viotti, in front of Piazza Castello.

The initial location of the building was supposed to be at Piazza XVIII December where the Rai headquarters is now located since the sixties. However, the final choice fell on the current location and was motivated by the simultaneous construction of the promising via Roma commercial street and by the barely concealed desire to symbolically oppose the monarchical power, historically represented by the Savoy Baroque buildings in the adjacent Piazza Castello.

- Tower Characteristics:

The project was conceived in 1933 by the joint collaboration of the architect Armando Melis de Villa and the engineer Giovanni Bernocco: a proven partnership for they were the designated duo for the headquarters of Reale Mutua Assicurazioni. It was drafted and approved in a very short time and got built at a rapid pace, even un-interrupted at night, which led to the rapid completion of the work from 1934 to 1940.

The tower held the record for the most inhabited building in Italy. It occupies just over two thirds of the block and consists of a lower body of 9 floors that develops along Via Giambattista Viotti up to Via Cesare Battisti, the whole culminates with the vertical body of the tower. In the north side with a view of Piazza Castello, the tower joins Vittozziano, the old building with porches that connects to via Roma.

The tower of 87 meters with the presence of the metal top antenna reaches 109 meters with a total of 19 levels. Currently, the basement, ground floor and first floor are occupied by the Mondadori Library.

The side elevations across Giambattista Viotti and Via Cesare Battisti retain the same characteristics of the tower, showing a horizontal language punctuated by light plaster casts alternating with large windows disrupting rythmically the bands of red brick. The noticeable angular balconies projecting towards via Roma and Piazza Castello feature extensive use of glass blocks.

- Alarming Past:

The building of choice should have a historical significance for the intervention to be perceived with shock when first seen.

Initially, the tower, was built with the intention of hosting, among other offices, the headquarters of the Fascist National Party (PNF). However, the party's headquarters eventually settled in Milan at first and then moved to Rome. Eventually, it got subsidized by Reale Mutua Assicurazioni. The insurance company is still the proud owner of the property, as evidenced by the large sign on the top.

During World War II, the building acted as an air raid siren to alarm the citizen of upcoming arial bombardments. Hence, the tower temporarily was associated with its alarming features. By analogy, this intervention would rappel this past aspect of the building, by having an engaging intervention, to alarm the citizens of our anthropogenic impact.

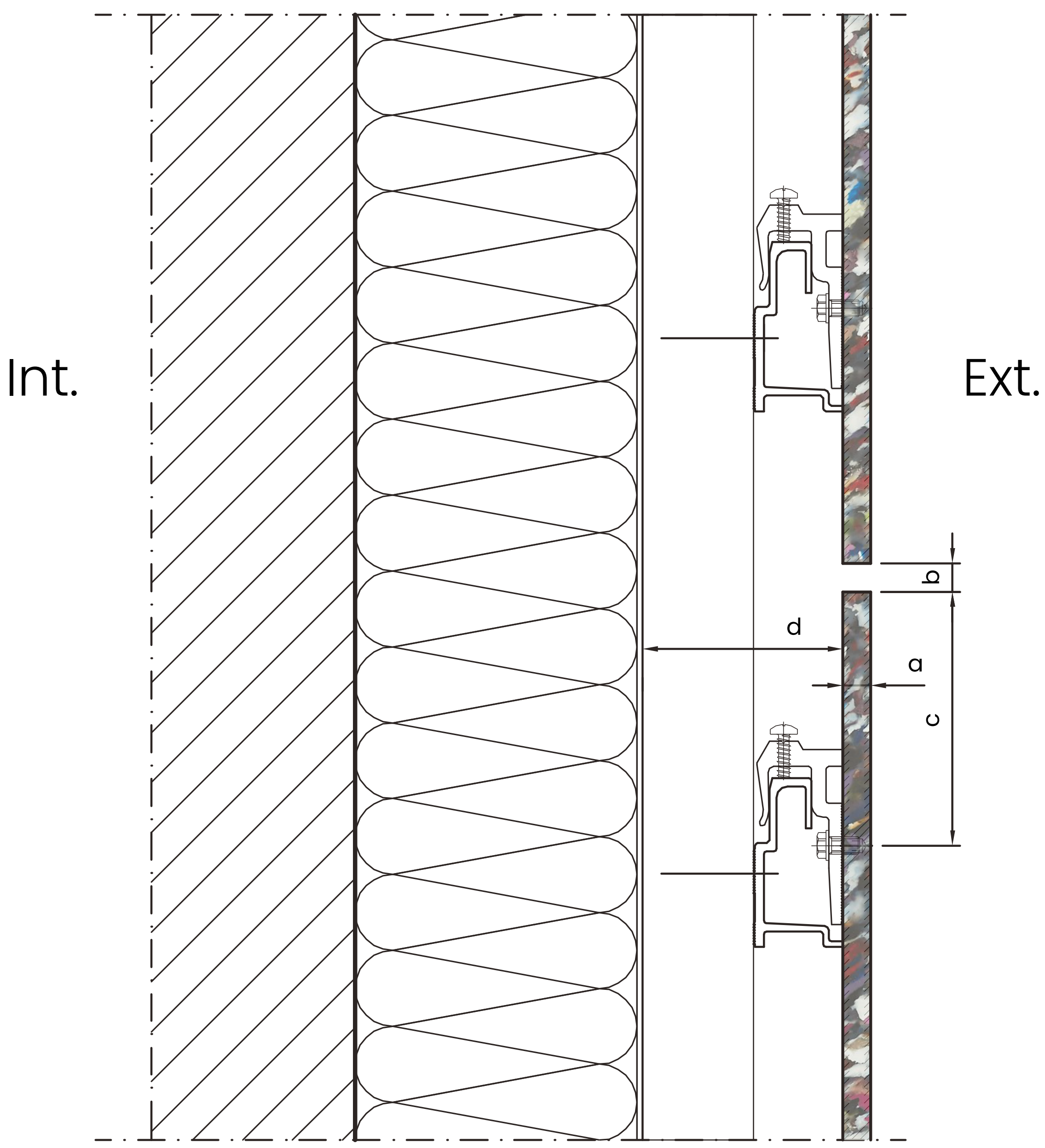
Therefore, by covering the rational tower not only are the Torinese going to question this intervention and indirectly revive the legacy of the tower by discussing about it in the news, at homes, restaurants, but they are also going to engage phenomenologically with the uncanny material. This interactive Anthropocene-aware intervention on the envelope of the tower, would further advance Turin's desired sustainable image.

Figure 45: The Torre Littoria under construction in 1933.
© n.d.

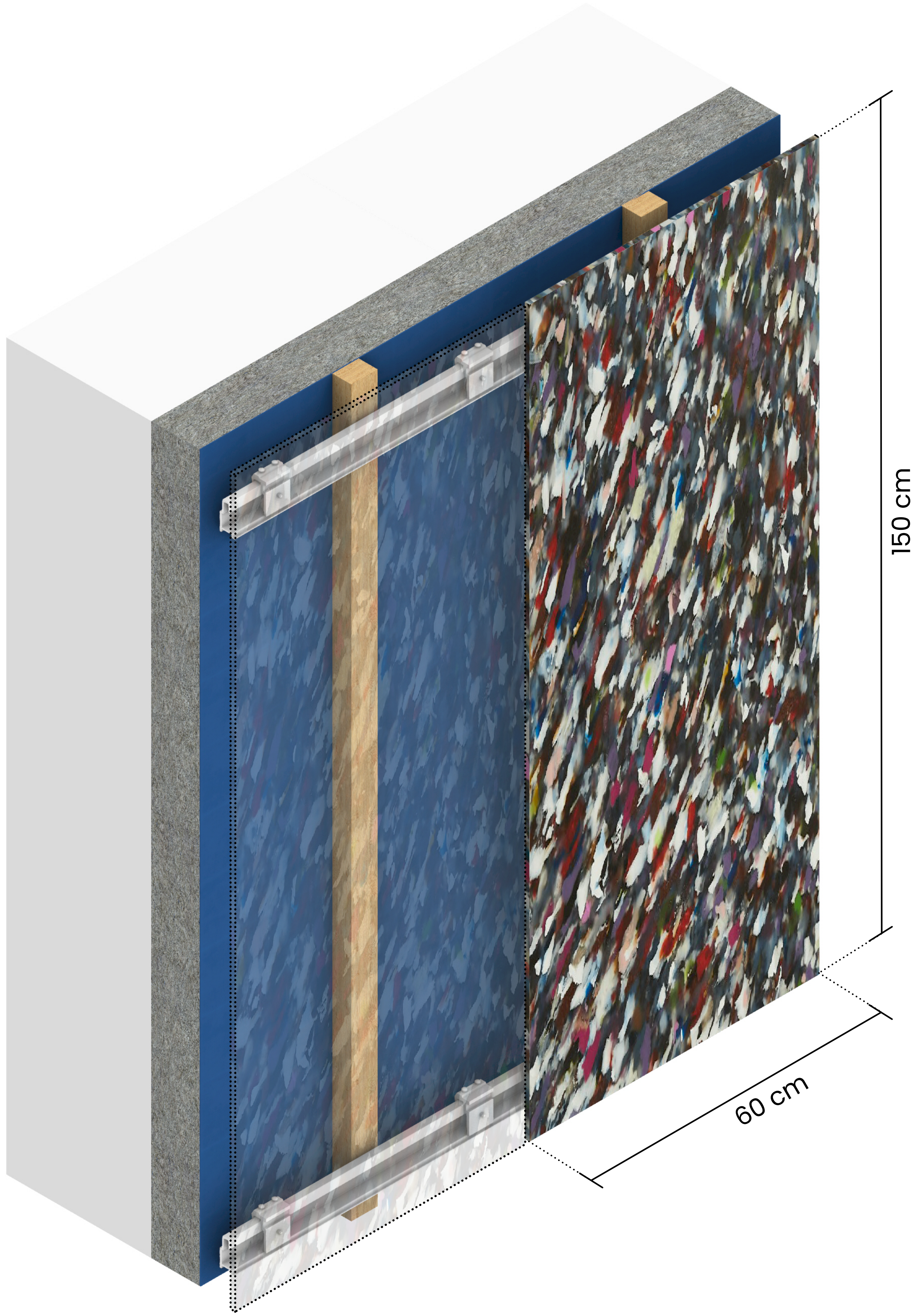
6.2 Context


via Giuseppe Garibaldi
via XX Settembre
via Giuseppe Barbaroux
Piazza Castello
via Pietro Micca
via Giovanni Battista Viotti
via Cesare Battisti
via Accademia delle Scienze
via Roma
via Antonio Bertola

6.3 Plastiglomerate Facade Panel Details



a	Rainscreen width: 12 mm
b	Joint between panels gap: 10 mm
c	Distance from the fixing axis to the edge of the panel: 75 mm min. - 125 mm max.
d	Air cavity between the rainscreen and the thermal insulation: 70 mm



6.4 Visuals

Envelope Application on an Existing Building in Turin

Envelope Application on an Existing Building in Turin

7. Conclusion

Hyperobjects such as the Anthropocene in particular, manifest partially their presence. The latter, recently revealed palpably through Plastiglomerate, was echoed by creative manipulations done in the humanities. These reactions demonstrate the double-sided nature of humans and their impact. We tend to want to solve the issues that face us, even when originally they were created by us. The existence of the word 'Anthropocene' itself, implies that we have become conscious of our presence on a global scale. For us now, to decide which path to follow knowing the responsibility we hold on our shoulders.

Optimistically, this thesis believes in the right decision to be made, hence, ventures in the case study of using Plastiglomerate as a building material for a ventilated facade application system in Turin, Italy.

Experience and research has shown that heterogeneous building materials are complicated to work with. However, they present great aesthetic qualities, rendering them appealing in their respective market. This heterogeneity, in the case of Plastiglomerate is moderated by its imitation in the lab, under controlled conditions. Moreover, its combination is reduced to three components: Plastic waste, Fine Aggregates, and a Binder.

These conditions, demand a unique type of plastic to be used. The plastic chosen in our case, had to be non-toxic. For this reason, it should be sourced from domestic uses. The selection of the plastic type was backed by previous experiments and proven to be abundant in Turin's current context of plastic waste stream. HDPE's selection and eventual usage could reduce the highest discarded un-recycled plastic type within the actual national plastic waste system. Furthermore, its low water absorption, high fire resistance, tensile strength, and durability renders it a good plastic type to be used for a rainscreen application.

The scarcity of natural sand used as fine aggregates in concrete, presents a non-negligeable environmental crisis. The fine aggregates chosen for the case study, would therefore, be sourced from the C&DW. Italy as of this study, has yet to find profitable uses for the C&DW. The lower cost of natural raw materials and their high quality are barriers that the recent european commission (COM (2003) 302) and national (CAM - Criteri Ambientali Minimi) regulations are tackling by promoting recycled materials in public building procurement. Hence, the proposed plastiglomerate rainscreen amongst other goals, hopes to encourage change in the Italian context relating to the waste generated in C&D. Findings, have shown that partially substituting natural sand with fine recycled aggregates is feasable, when composing the right treatment, variety in sizes, and replacement rate.

For aesthetic purposes, sodium silicate was chosen to be used as the binder. Its translucid properties, along with its curing properties, adhesiveness with HDPE in particular, and chemical stability, would actively participate in prolonging the rainscreen's durability, hence its sustainability.

The Plastiglomerate rainscreen would be installed following the concept of Design for Disassembly. This is due to the fact that Plastiglomerate is hard to recycle. Practically, the Plastiglomerate rainscreen would be mechanically fastened in order to be easily detached at the end of service life.

For future inquiries, evidence-based investigations should be made in a lab in order to verify the properties of plastiglomerate used for rainscreen purposes according to ATSM standards. (Notably: Particulate Matter Resistance, Durability, Water Absorption, UV resistance, Flexural strength). Additionally, the performance requirements according to the EU regulatory framework for construction products (Regulation (EU) No. 305/2011 of the European Parliament and of the Council of 9 March 2011. Furthermore, the harmonized conditions for the marketing of construction products following the Council Directive 89/106/EEC).

- Experiment with other abundant un-recycled types of plastic, such as PET, and PP.

- Different ratios of Plastic / FRA and binder amount should be investigated for rainscreen purposes.

- Cohesion between different FRA sizes and the plastic type.

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