

research plan

aE studio



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Building with Recycled Plastic Materials: Designing Modular Student Housing and Exploring Circular Solutions



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keywords

Recycled Plastic, Materials, Plastic Waste Recycling, Modular Housing, Design, Circularity, Sustainability, Architecture

The choice of the Architectural Engineering studio is based on the development of my growing fascination, which I want to explore further within the context of the architectural built environment. This studio provides the perfect opportunity to deepen my research into the role of architecture in addressing today's challenges. Central to my motivation is the pursuit of a more sustainable future through innovative design approaches, and I am excited to participate in a studio that encourages students to address these critical issues.

My fascination focuses on the recycling of waste streams and materials within architecture and the built environment, an important aspect of sustainable design and circular economy initiatives. When writing my history thesis, 'Construction Waste: A Human Perception Instead of Actual Reality?', I was able to explore this topic further and use it as a starting point to change society's perception of waste and encourage the wider use of residual materials in the construction sector.

During my semester abroad at the Instituto Superior Técnico in Lisbon in spring 2024, my focus became more material-specific, particularly through the course 'Circular Economy for Plastics'. This course introduced different techniques for both mechanical and chemical recycling of plastic waste streams and highlighted the opportunities and challenges of working with recycled plastic materials. As I delved more into this subject, I began to see the potential of application of recycled plastics in construction and building design. Although some projects and research are already emerging in this field, it is still in its early stages and addresses a complex and urgent environmental problem. This challenge inspired me to focus my graduation project on exploring and promoting the use of recycled plastic materials in building design and construction.

By choosing this studio, I see the ideal platform to combine my interest in sustainable innovation with my growing expertise in recycled materials to contribute to a future where environmental responsibility is integrated into architectural practice.

argumentation aE studio choice

general problem statement

Plastic is a material that has become deeply embedded in everyday life due to its versatility and widespread use in both short- and long-term products. However, our current use of plastics is not sustainable. The still increasing production of plastic has led and will lead, if not handled responsibly, to a huge increase in plastic waste.

Since most plastics are not biodegradable, they remain in the environment for hundreds of years, leading to serious pollution problems, including microplastic, contamination of oceans and harming ecosystems. Moreover, plastic production and disposal are energy-intensive and dependent in most cases on fossil fuels, contributing significantly to greenhouse gas emissions leading to further climate change. Since most plastic waste is not recycled, it often ends up in landfills, is incinerated or leaks in the environment, exacerbating degradation.

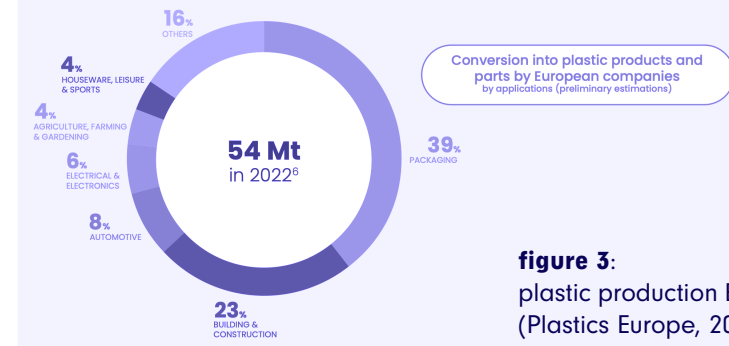


figure 3:
plastic production Europe per activity (Plastics Europe, 2023)

Although plastic recycling offers an important solution to the problem of plastic waste, current recycling efforts face challenges. Less than one-fifth of plastic waste is recycled (Amadei et al., 2023) due to factors such as:

- The collecting, sorting and processing of plastic waste are inefficient, leading to large amounts of plastics not being recycled and high costs.
- The complex variety of plastic types and polymer compositions, each with different properties, making efficient recycling difficult.
- Recycling plastics is often less economically viable compared to producing new (virgin) plastics.
- Contamination by food, adhesives, labels, and other residues during use, makes efficient recycling of plastics harder.
- The degradation of material quality after each recycling cycle.

(Hopewell et al., 2009)

Despite these challenges, improvement of recycling technologies and methods today offer the potential to turn plastic waste into valuable resources if the right applications and systems can be developed. According to Ragaert et al. (2019), plastics are recognized as one of the most promising materials for reducing the carbon footprint in Europe, alongside other key materials such as steel, aluminum, cement, and mortar.

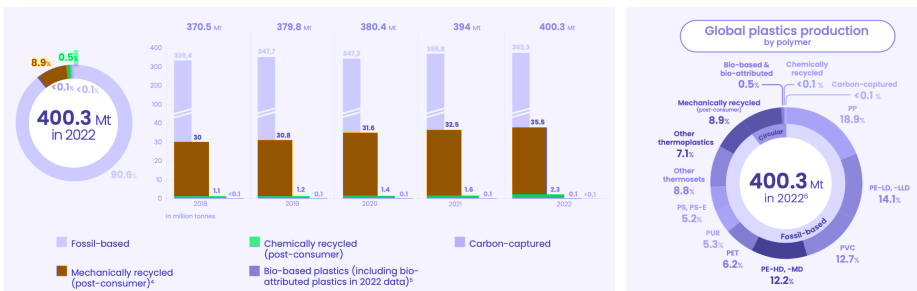
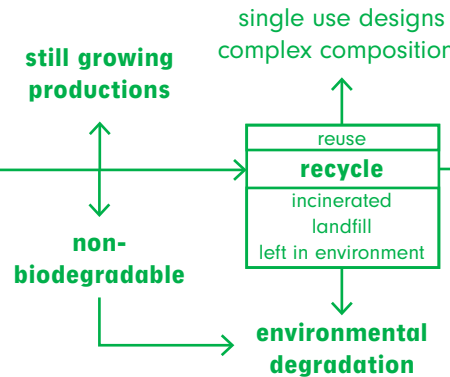


figure 1 and 2: plastic production growth world wide (by polymer) (Plastics Europe, 2023)

the problem
plastic pollution



promising resource to reduce carbon footprint

↑

the solution
recycle plastic

↑

better management waste streams

The construction industry is a major contributor to environmental degradation, both in terms of resource consumption and waste generation, with 22.9% of Europe's plastic waste coming from building and construction activities (Janssens, 2024) With an increasing demand for sustainable materials, there is a growing interest in including recycled plastics in the design and construction of buildings. However, research in this area is still limited, mainly due to concerns about structural integrity and durability of these materials. Despite these challenges, research shows promising opportunities for utilizing recycled plastics in architecture. Rethinking the use of recycled plastic waste streams in building design, the industry can help reduce environmental impacts while exploring aesthetic and technical design opportunities.

Recycled plastic materials such as plastic lumber, pavers, and bricks have already found applications in decking, fencing, and even infrastructure, proving to be durable and resistant to decay. Another innovative approach includes the use of plastic waste in composite materials for insulation, roofing, and other building components. (Awoyera & Adesina, 2020) These developments not only help manage plastic waste streams but also reduce carbon emissions and energy consumption, contributing to circular economy principles.

For the construction industry to effectively integrate recycled plastics, further research is needed to meet building standards while ensuring environmental benefits, like reducing reliance on non-renewable resources. Technological innovations and research, and collaborations between amongst others, researchers, architects, and industry stakeholders can address quality concerns, making recycled plastics a vital component of sustainable building solutions and inspire the broader sustainable vision applying residual materials as resources.

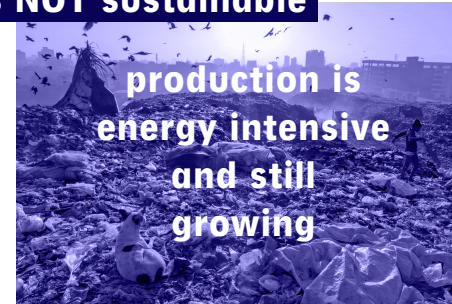
building and construction
produces **22.9%**
EU plastic waste

the opportunity

building with recycled plastic materials



our current use of plastics harms the environment and is NOT sustainable



design objective



figure 4: TU Delft Campus Plan 2040

The aim of this project is to design a modular housing system using recycled plastic materials, with a circular approach applied on a national scale and utilizing the (existing) plastic recycling infrastructure in the Netherlands. The system will create low-impact temporary housing units for 1-2 person student households on the TU Delft campus, addressing the urgent need for student housing while exploring scalable, sustainable solutions. (Van Der Meer, 2023)

This modular housing strategy will be based on a catalogue of recycled plastic building components, offering flexibility in design while ensuring that these structures can be easily disassembled, reconfigured and recycled.

The choice of TU Delft is strategic, given the need of temporary student housing due to housing shortage and the availability of relevant technological expertise. The project also provides an opportunity for ongoing research and development, potentially using on-site facilities for production, repair and recycling of components. This on-site manufacturing centre will explore the integration of circular technologies and systems for the context itself and can therefore form an example model that can inspire future sustainable (housing) projects.

Besides sustainability, the project will focus on creating functional and adaptable living spaces that meet aesthetic and design standards, providing students with flexible housing solutions that fit within a sustainable framework.

design question

thematic research focus

How can recycled plastic materials and associated production and building techniques be integrated into modular and circular design and construction of small housing units in Delft, the Netherlands?

technology

The project explores the use of recycled plastics in modular housing, focusing on related manufacturing techniques such as 3D printing, plastic extrusion and compression molding and injection molding. It investigates how the allocated materials can be used to create modular units that are reconfigurable, reusable and recyclable. Key to this is an understanding of recycling technologies and how recycled plastics can be processed into structural and non-structural building components and how these could be (dis-)assembled.

context

Delft is selected as location for this initiative due to TU Delft's need for temporary student housing on its campus. This small-scale student program provides an ideal opportunity to test the application of recycled plastic materials in modular housing strategies. In addition, having TU Delft as a nearby research institute allows for ongoing exploration and development of using recycled plastic materials in building construction.

use

Designed for student units of 1-2 people, this modular housing system provides sustainable living spaces. The idea is to develop a catalogue of modular components that allow students to adapt elements of the unit to personal needs in limited circumstances, when possible a lease or exchange system can be developed around this. The module system is intended for temporary use, after which the units can be reconfigured, reused or (partially) recycled when no longer needed. The project is also investigating the scalability of this solution, by considering how many students can be accommodated with maximum sustainability.

research objective

This research investigates the potential, performance and practical applications of recycled plastic materials and associated manufacturing techniques within the residential design and construction sector. While innovative projects have demonstrated the feasibility of these materials in architecture, their wider technical performance and environmental impact in various parts of housing construction remain underexposed. For example, companies such as Uppact produce recyclable building materials, like boards and beams, made of plastics that are difficult to recycle (Uppact, 2022), and Pretty Plastics is specialized in facade tiles made of 100% recycled PVC (Pretty Plastic, 2024). However, these efforts mainly focus on limited product types and specific applications, leaving a gap in understanding how recycled plastics could be used in other structural or design components of simple, modular housing designs. This research will evaluate the technical, design and environmental parameters of these materials - such as structural integrity, durability, thermal performance, fire resistance, visual appeal, ease of production and sustainability - to discover opportunities for their wider integration into simple and sustainable modular housing construction.

A core focus of this research is the circularity and sustainability of these materials to ensure that they not only perform well technically, but also align with broader goals of sustainable construction. The findings will help determine if these materials can replace or complement traditional building materials in cost-effective, low-carbon housing. If they do not meet the requirements, it is worth exploring possible improvements to the material or considering mixing it with other materials to better achieve the durability and performance goals.

Finally, the results of this research will serve as a basis for a design proposal for modular and circular housing units that maximize the use of recycled plastics in components. My hypothesis is that the results will provide practical guidance for integrating these materials into building systems and demonstrate their potential as viable alternatives to traditional materials in a variety of residential applications.

research question

What recycled plastic materials and related production techniques are available to be used in housing design and construction?

sub-questions

- 1 What **recycled plastic materials and related production techniques** are currently available?

location: netherlands
- 2 What **parameters** can be used to evaluate the technical and design performance, and environmental potential of the materials in housing design and construction?

↓
technical **design** **sustainable**
- 3 How do the materials **perform** based on **key** technical, design and environmental **parameters**?
- 4 How can the materials based on **key parameters** be **applied in housing** design and construction?

The Netherlands has set the ambitious goal of achieving a fully circular economy by 2050, which requires a transformative approach to waste management aligned with the principles of the R-ladder—Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover. Currently, a significant proportion of plastic waste is incinerated for energy recovery or landfilled, resulting in the loss of valuable resources and harmful environmental impacts. (Janssens, 2024) Prioritizing recycling, which ranks lower on the R-ladder than waste prevention and reuse, is nonetheless a more sustainable alternative to incineration and landfill. It minimizes waste, reduces reliance on virgin materials, and supports both national and international sustainability goals.

From a social perspective, the design objective of integrating recycled plastic into modular housing directly addresses pressing issues of environmental sustainability and resource efficiency. The project aims to create temporary student housing at TU Delft to meet the need for housing while demonstrating the viability of recycled materials in construction. This initiative not only meets the needs of students, but also contributes to broader sustainability goals and demonstrates how innovative design can reduce waste production while reducing environmental impact.

The project has both specific and general aspects. Although it focuses specifically on the design of student housing, the principles and findings can be applied to various housing and other building solutions. By investigating advanced manufacturing techniques and material applications, the research aims to inform a wider audience, including architects, builders and policy makers, about the potential of recycled plastics in the building sector.

Ultimately, this design objective is not just about building homes; it is about promoting sustainability and resourcefulness that can inspire future building projects.

reflection on relevance

the impact

- reduce CO₂ emissions
- reduce waste productions
- inspire future projects

methodology

The research will employ multiple methods:

Case study analysis: Analyzing and identifying case studies of buildings and projects that incorporate recycled plastic waste streams and examining their influence on housing design.

Literature review: Investigating the various plastic waste streams in combination with the available production techniques and understanding their specific possibilities for application in the built environment.

Field research: Investigating the available plastic waste streams and production techniques and assessing their potential for application in housing design and construction.

Material analysis: Understanding the composition and properties of available recycled plastic materials, such as their strength, stiffness, durability and other housing-specific aspects such as fire resistance, thermal insulation, UV stability, with the option to request and analyse samples if available and necessary.

Comparative analysis: Compare two or more cases, options or variables to understand their similarities, differences and the factors influencing the outcomes of the study.

Research by design: Making it possible to investigate in practice how recycled plastic materials can be integrated into housing design, using a modular student housing unit as a baseline.

	sub-question	methodology	
1	What recycled plastic materials and related production techniques are currently available?	case study analysis literature review field research	
2	What parameters can be used to evaluate the technical and design performance, and environmental potential of the materials in housing design and construction?	literature review field research material analysis	
3	How do the materials perform based on key technical, design and environmental parameters ?	field research material analysis comparative analysis	
4	How can the materials based on key parameters be applied in housing design and construction ?	research by design case study analysis	



application	data
used to explore the recycled plastic materials and related production techniques available or potentially suitable for use in housing design and construction.	available materials and techniques in The Netherlands
used to identify key parameters for evaluating the technical performance and environmental potential of recycled plastic materials needed in housing design and construction. Together, these parameters form the basis for assessing the suitability of these materials for housing applications. The parameters will be weighted according to their relevance in relation to specific requirements of modular student housing, ensuring that the evaluation prioritizes factors that are most critical for practical application in the design project.	list of parameters based on the users (TU Delft students) needs, covering technical, design, and sustainability aspects. The relevance of parameters will be rated 1 to 10 to prioritize materials for the design.
conducted to evaluate the technical properties and sustainability performance of recycled plastic materials and related production techniques. These methods will be used to investigate their potential applications in housing design and construction. Technical properties (including structural, durability, weather and fire resistance, etc.) will be analyzed along with their environmental impacts, such as carbon emissions, circularity and recyclability. The results of these assessments will then be compared to determine which materials offer promising sustainable alternatives for use in building design and construction.	table with all available key parameters per material. Performance will be rated to determine suitability for housing applications.
used to investigate the application of the promising recycled plastic materials, based on the identified parameters. Based on these alternatives, application strategies can be developed for the materials to be applied in a 'simple', modular housing system. In this process modular building components made from recycled plastics can be defined in forms and functions. This will show how the materials can be used effectively in housing design and construction.	application of most suitable materials in a possible component design as part of a modular home design based on their performance in key parameters

design relevance

- **context** decides boundaries
 - local materials
 - local techniques

- **use(r)** decides relevance of parameters

- **technology** decides which materials can be used for application and how



This research will determine the maximum extent to which recycled plastic materials can be integrated into a modular housing system for student accommodation. The research will determine the most feasible applications of these materials in different building components and assess their technical, aesthetic and environmental design parameters.

If full application of recycled plastic is not feasible for certain structural or functional elements, the research will explore fallback solutions, such as composite materials that combine recycled plastic with other residual materials.

The results will provide a practical basis for the design process by providing possible material applications with detailed parameters such as structural integrity, thermal performance and recyclability. In the further design process, this will guide the development and configuration of both individual module designs and the relationship between different modules in the overall housing system.

The research will also identify potential recycling and manufacturing technologies that can be implemented on-site on campus or has to be found elsewhere in the Netherlands. This will help map strategies and define the boundaries of the circular system, determining which technologies can support local processing and which need external sources.

Ultimately, this research will provide a comprehensive toolkit for integrating recycled plastics into modular homes, shaping both material selection and manufacturing strategies while ensuring sustainability and circularity in the design process. In addition, this approach could demonstrate if recycled plastic materials can reduce the environmental impact and inspire others to explore the potential of (plastic) waste in building design and construction.

expected results

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literature

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figures

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additional literature

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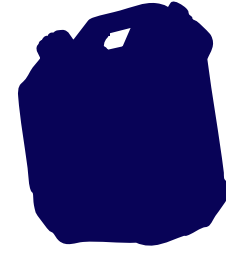
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planning



october			november			december			january								
7 - 13	14 - 20	21 - 27	28 - 3	4 - 10	11 - 17	18 - 24	25 - 1	2 - 8	9 - 15	16 - 22	23 - 29	30 - 5	6 - 12	13 - 19	20 - 26	27 - 2	
	research plan draft 17 okt.	start thematic research collecting contacts and information regarding parameters	start thematic research & prepare P1 context and user research for defining research parameters for design	P1 5 nov.	structural content & chapter 1 material & technology selection	chapter 1 & 2 parameter selection	chapter 2 & 3 parameter analysis	chapter 4 application analysis based on context and user needs	chapter 4 research by design form and function components	research draft 20 dec.		start exploring design configurations reflect on research what is missing in the catalogue?	start design	process feedback finalize research design concept configurations	prepare P2 reflect on research reflect catalogue & configuration	P2 20 - 31 jan.	

research

design

february			march			april			may			june											
3 - 9	10 - 16	17 - 23	24 - 2	3 - 9	10 - 16	17 - 23	24 - 30	31 - 6	7 - 13	14 - 20	21 - 27	28 - 4	5 - 11	12 - 18	19 - 25	26 - 1	2 - 8	9 - 15	16 - 22	23 - 29			
design development context & system focus			design development module building configurations & assembly focus			design development module building configurations & assembly focus			design development circular system focus			design development details focus			prepare P3 present design development			P3 24 mar. - 11 apr.					
reflect on design development start finalizing			final prototyping			final drawings			prepare P4 all drawings and prototypes ready for presenting			P4 12 - 28 may			prepare P5 improve presentation drawings			prepare P5 improve presentation model and prototypes			P5 16 - 27 jun.		



glossary of keywords

Recycled Plastic

Plastic that has been processed and re-manufactured from discarded plastic materials and has potential as a sustainable building material.

Materials

Substances or components, with individual properties, used in building design and construction, which in this context are derived from recycled plastics.

Plastic Waste

Discarded plastic materials, often harmful to the environment, which your project seeks to repurpose through recycling for sustainable construction.

Modular housing

A construction system in which housing units are built using prefabricated components that can be easily assembled, disassembled and relocated, offering significant benefits in flexibility, adaptability, and circularity by simplifying repairs, replacements, and reconfiguration.

Design

The creative process of planning functional structures and systems, in this case focusing on housing using sustainable materials and modular techniques.

Circularity

A sustainable system of production and consumption that aims to minimize waste and keep materials in use through recycling, reusing, and repurposing.

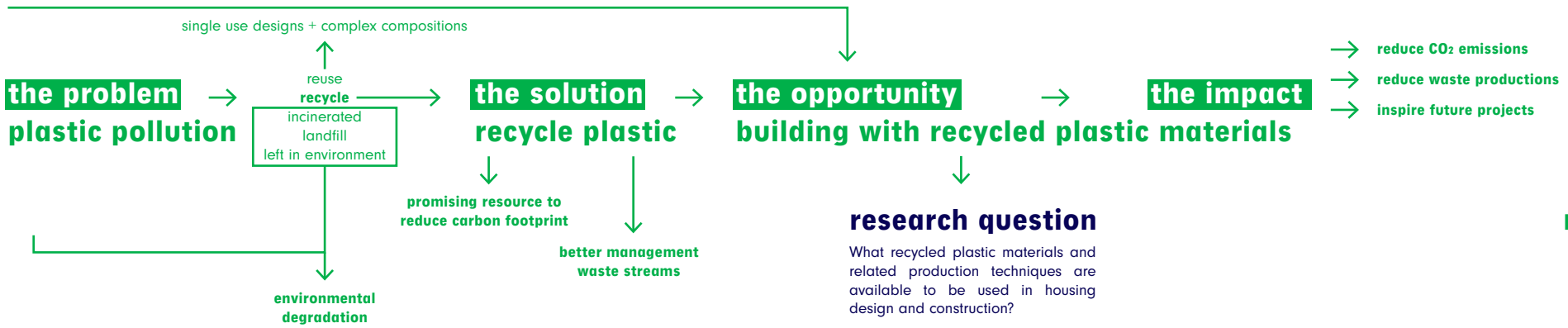
Sustainability

Practices that meet present needs without compromising the ability of future generations to meet their own needs, with recycling it focusses on environmental conservation and resource efficiency.

Architecture

The art and science of designing and constructing buildings, emphasizing both form and function. The research aims to contribute to the field of architecture by demonstrating how recycled materials can be integrated into housing design, pushing the boundaries of sustainable building practices.

building and construction
produces **22.9%**
EU plastic waste



research + design diagram

qualitative data

1 What **recycled plastic materials and related production techniques** are currently available?

location: netherlands
→ context

2 What **parameters** can be used to evaluate the technical and design performance, and environmental potential of the materials in housing design and construction?



rate relevance for design 1 - 10

3 How do the materials **perform** based on **key** technical, design and environmental **parameters**?

helps decide which material for application → technology

4 How can the materials based on **key parameters** be **applied in housing** design and construction?

methodology

case study analysis
literature review
field research
material analysis

field research
material analysis
comparative analysis

research by design
case study analysis

quantitative data

design question

How can recycled plastic materials and associated production and building techniques be integrated into modular and circular design and construction of small housing units in Delft, the Netherlands?

→ technology
→ context
→ use



start design

- building component catalogue
- set of parameters for further configuration

