Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	**Kasım Berk Adsan**
Student number	5957869

Studio		
Name / Theme	Building Technology Graduation Studio AR3B025 / Material and design optimization of injection-molded reinforcement spacers using plastic residues of WEEE recycling	
Main mentor	Dr. Telesilla Bristogianni	Structural Design
Second mentor	Dr. Marcel Bilow	Façade and Product Design
Argumentation of choice of the studio	I perceive Building Technology as an interdisciplinary bridge between architecture and engineering. The graduation studio offers the opportunity to evaluate a material loop from inception to completion comprehensively. Therefore, it enables a deeper focus on the material and product design for the construction industry, as my mentors' specialities include structural design and product design. The studio enables the study for one of the R-ladder implementations -recycling-for a specific material. The thesis aims to benefit from these opportunities and create an optimal design solution for recycled architectural components for the construction industry.	

Graduation project	
Title of the graduation project	rec-HERO
Goal	
Location:	Not Defined
The posed problem	The problem is the inefficient recycling processes and accumulation of unrecycled plastic waste, which poses environmental and economic challenges. Current recycling technologies struggle to handle mixed and contaminated post-consumer plastic wastes, which forces a substantial portion of unrecycled plastic to be sent to incineration or landfill. The regulations in the Netherlands necessitate incineration as the final resort, which has a lower environmental impact than landfills. However, the emissions from incineration are three times the total mass of plastic waste worldwide, making recycling the preferred option (Vollmer et al., 2020). Globally, about 10% of plastics are being recycled, and the overall efficiency of the 10% portion is 50% (Lange, 2021). The unrecycled plastic waste from recycling practices presents a significant potential as a material source for the construction industry, which has the second highest plastic demand (Ragaert et al., 2017). The existing limitations for the unrecycled plastic fraction include: ▪ Contamination with organic and inorganic fractions

	▪ Unknown polymer compositions and ratios ▪ Polymer degradation Therefore, addressing this issue more effectively is imperative by utilising unrecycled plastic waste into another service life as an architectural component.
Research questions	Research Question: How can plastic residues from WEEE recycling be processed into an optimized injection-moldable building component? Sub-questions ▪ What is the state of the art of plastic manufacturing and plastic recycling? ▪ What are the primary challenges of recycling plastics from one waste stream? ▪ What are the material characteristics of WEEE plastic waste? ▪ What are the technical requirements and limitations of injection molding for plastics? ▪ How does the presence of contamination and unknown polymer composition affect the injection molding behavior of WEEE plastic waste? ▪ What architectural applications are suitable for contaminated and mixed plastic? ▪ What parameters influence the structural performance, moldability and concrete compatibility of reinforcement spacers?
Design assignment	The design assignment is to develop a structurally functional, injection-molded reinforcement spacer for concrete construction using the unrecycled plastic waste fractions from the WEEE (waste electrical and electronic equipment) waste stream. The project aims to transform contaminated and mixed plastic waste into a functional, non-exposed component for concrete construction. The reinforcement spacer, not subjected to fire risk, weathering or UV radiation, makes it a suitable target product to prove the potential of using contaminated and low grade plastics for industrial scalability. The project adopts a dual-track methodology, combining bottom-up material research with top-down product design optimization. Each track is evaluated under a distinct set of parameters throughout the thesis. The material track focuses on developing a workable recipe for injection molding through various experiment setups that mimic both mechanical recycling and injection molding. Simultaneously, the product track begins with the understanding of the functional and structural requirements of reinforcement spacers to set up parameters. The parameters are set to iteratively optimize the design for real-life applications. The tracks are set to be in a feedback loop that continuously informs one another for accurate testing and simulations. Therefore, the reinforcement spacer is a validated, optimized prototype that showcases a practical business case of plastic waste that otherwise would be incinerated.

Process

Method description

The thesis consists of three main phases, including computer work and laboratory:

Phase 1 - Literature Review

- Identifying the state-of-the-art plastic manufacturing and recycling technologies, including mechanical and chemical recycling.
- Comparing global, EU, and the Netherlands' waste rates and current waste flows.
- Analysing the waste streams -waste electrical and electronic equipment, end-of-life vehicles, packaging- and their common polymer ratios.
- Reviewing existing prototypes and design evaluation criteria to determine potential design methodologies.
- Conducting interviews with plastic recycling companies to collect data on the sorting and recycling stages to identify the source of unrecycled plastic flows while obtaining plastic waste samples for the experimentation phase.
- Reviewing building components suitable for mixed and contaminated plastic use.
- Identifying the state-of-the-art injection molding of plastics and simulation approaches for testing applicability.
- Reviewing existing regulations and performance benchmarks for concrete construction and reinforcement spacers.

Phase 2 – Material Experimentation & Product Development (Dual-track Methodology)

Material Experimentation Track

- Analyzing and documenting the physical and chemical characteristics of fridge and small domestic appliances lines of the WEEE stream.
- Doing Differential Scanning Calorimetry (DSC) and Fourier-Transform Infrared spectroscopy on manually selected polymers from each waste line.
- Mimicking the key steps of mechanical recycling for plastics in a low-tech method: density-based float-sink separation and manual color sorting.
- Using the FT-IR technique to create polymer batches suitable for injection molding.
- Experimenting with all polymer blends, manual color-sorted polymer blend, density-sorted polymer blends, FT-IR identified polymer/polymer blends with three respective setups: rapid testing that mimics injection molding principles, a manual-pressured injection molding machine, and a compressor-powered injection molding machine.
- Evaluating outcomes based on material performance parameters of mixing, morphology, degradation, polymer blending, polymer sorting and identification results, developing an optimal recipe for injection molding.

Product Development Track

- Evaluating the mainstream designs and properties of reinforcement spacers and their usage.
- Establishing a set of evaluation parameters that will be used to verify the optimal application context (beam/column) and design of the spacer.
- Asses the parameters of contact area, flexibility for rebars, plastic use per product, injection flow analysis, compressive test analysis, and Charpy impact analysis both by simulation and physical tests.
- Develop alternative methods with resin printing to create a mold applicable for injection molding and high temperature, pressure values.
- Continuously adapt the simulation conditions based on real-time data and outcomes from the material experimentation track.
- Assign an overall grade for each reinforcement spacer design and choose the final design for developing the resin mold for injection and to fabricate the full-scale mockup.

Phase 3 – Application

- Selecting the most promising material-design combination based on cross-analysis of the data from both tracks.
- Testing the resin mold's workability, dimensional accuracy and surface quality for the final injection molding.
- Validating the effectiveness of the decision-making parameters for the dual-track methodology.
- Presenting a 1:1 scale proof of concept with varying aggregate sizes for concrete with the final design to assess the flow and the final surface performance.
- Comparing the recycling/recovery rates and system diagram of the thesis proposal based on the existing EPD data.
- Suggesting alternative methods and possibilities for future studies for contaminated WEEE plastics and injection molding.

Literature and general practical references

Akkouri, N., Baba, K., Simou, S., ELfarissi, L., & Nounah, A. (2020). Recycled thermoplastics modified bitumen improved with thermoplastic elastomer. E3S Web of Conferences, 150, 02015. https://doi.org/10.1051/e3sconf/202015002015

Arya, S., Sharma, R., Rautela, R., & Kumar, S. (2023). Conversion of obsolete keyboard plastics mixed with egg shells and fly ash into concrete brick cubes. Sustainable Energy Technologies and Assessments, 57, 103253. https://doi.org/10.1016/j.seta.2023.103253

Awasthi, A. K., Shivashankar, M., & Majumder, S. (2017). Plastic solid waste utilization technologies: A Review. IOP Conference Series: Materials Science and Engineering, 263, 022024. https://doi.org/10.1088/1757-899X/263/2/022024

Berwald, A., Dimitrova, G., Feenstra, T., Onnekink, J., Peters, H., Vyncke, G., & Ragaert, K. (2021). Design for Circularity Guidelines for the EEE Sector. Sustainability, 13(7), 3923. https://doi.org/10.3390/su13073923

Bressanelli, G., Saccani, N., Perona, M., & Baccanelli, I. (2020). Towards Circular Economy in the Household Appliance Industry: An Overview of Cases. Resources, 9(11), 128. https://doi.org/10.3390/resources9110128

Celik, Y., Shamsuyeva, M., & Endres, H. J. (2022). Thermal and Mechanical Properties of the Recycled and Virgin PET—Part I. Polymers, 14(7), 1326. https://doi.org/10.3390/polym14071326

ÇetiN, E., & Türkan, O. T. (2024). Material recycling of acrylonitrile butadiene styrene (ABS) from wiring devices using mechanical recycling. Sustainable Chemistry for the Environment, 6, 100095. https://doi.org/10.1016/j.scenv.2024.100095

Chukwuemeka, D., Daniel, I., Ugochi, A., & Sandra, C. (n.d.). Enhancing Effective Circulation and Production Using Architectural Stratergies in Plastic Waste Recycling and Production Plants.

Dorigato, A. (2021). Recycling of polymer blends. Advanced Industrial and Engineering Polymer Research, 4(2), 53–69. https://doi.org/10.1016/j.aiepr.2021.02.005

Dornfeld, D. A., & Linke, B. S. (Eds.). (2012). Leveraging Technology for a Sustainable World: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, University of California at Berkeley, Berkeley, USA, May 23 - 25, 2012. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-29069-5

Elmosaad, Y. M., Al Rajeh, A. M., Llaguno, M. B. B., Alqaimi, S. S., Alsalman, A. M., Alkishi, A. Y., Hussain, H., Alhoudaib, M. A., Alnajim, O. S., & Belal, S. (2023). Self-Reported Household Waste Recycling and Segregation Practices among Families in Eastern Region of Saudi Arabia: A Cross-Sectional Study. International Journal of Environmental Research and Public Health, 20(3), 1790. https://doi.org/10.3390/ijerph20031790

Engelsmann, S., Spalding, V., & Peters, S. (2012). Plastics in Architecture and Construction.

Faraca, G., Martinez-Sanchez, V., & Astrup, T. F. (2019). Environmental life cycle cost assessment: Recycling of hard plastic waste collected at Danish recycling centres. Resources, Conservation and Recycling, 143, 299–309. https://doi.org/10.1016/j.resconrec.2019.01.014

Fenwick, C., Mayers, K., Lee, J., & Murphy, R. (2023). Recycling plastics from e-waste: Implications for effective eco-design. Journal of Industrial Ecology, 27(5), 1370–1388. https://doi.org/10.1111/jiec.13409

Gabriel, D. S., & Tiana, A. N. (2020). Mechanical Properties Improvement of Recycled Polypropylene with Material Value Conservation Schemes Using Virgin Plastic Blends. Materials Science Forum, 1015, 76–81. https://doi.org/10.4028/www.scientific.net/MSF.1015.76

Gaggino, R., Kreiker, J., & Filippin, C. (2018). The Comprehensive Comparison of Thermal and Physical-Mechanical Properties of the Recycled Rubber andPlastic Roofing Tiles versus Roofing Tiles Made withDifferent Traditional Materials. Hindawi, 11.

Goh, P. G., Maghfouri, M., Onn, C. C., & Loo, S. C. (2022). Life cycle assessment on recycled e-waste concrete. Case Studies in Construction Materials, 17, e01412. https://doi.org/10.1016/j.cscm.2022.e01412

Golsteijn, L., & Valencia Martinez, E. (2017). The Circular Economy of E-Waste in the Netherlands: Optimizing Material Recycling and Energy Recovery. Journal of Engineering, 2017, 1–6. https://doi.org/10.1155/2017/8984013

Jadhao, P. R., Ahmad, E., Pant, K. K., & D. P. Nigam, K. (2022). Advancements in the field of electronic waste Recycling: Critical assessment of chemical route for generation of energy and valuable products coupled with metal recovery. Separation and Purification Technology, 289, 120773. https://doi.org/10.1016/j.seppur.2022.120773

Jia, C., Das, P., Kim, I., Yoon, Y.-J., Tay, C. Y., & Lee, J.-M. (2022). Applications, treatments, and reuse of plastics from electrical and electronic equipment. Journal of Industrial and Engineering Chemistry, 110, 84–99. https://doi.org/10.1016/j.jiec.2022.03.026

Kawecki, D., Scheeder, P. R. W., & Nowack, B. (2018). Probabilistic Material Flow Analysis of Seven Commodity Plastics in Europe. Environmental Science & Technology, 52(17), 9874–9888. https://doi.org/10.1021/acs.est.8b01513

Khalid, M. Y., Arif, Z. U., Ahmed, W., & Arshad, H. (2022). Recent trends in recycling and reusing techniques of different plastic polymers and their composite materials. Sustainable Materials and Technologies, 31, e00382. https://doi.org/10.1016/j.susmat.2021.e00382

Lange, J.-P. (2021). Managing Plastic Waste, Sorting, Recycling, Disposal, and Product Redesign. ACS Sustainable Chemistry & Engineering, 9(47), 15722–15738. https://doi.org/10.1021/acssuschemeng.1c05013

Luijsterburg, B., & Goossens, H. (2014). Assessment of plastic packaging waste: Material origin, methods, properties. Resources, Conservation and Recycling, 85, 88–97. https://doi.org/10.1016/j.resconrec.2013.10.010

McGuirk, J., & Idenburg, F. (2019). Home Futures: Living in Yesterday’s Tomorrow.

Mendes Campolina, J., São Leandro Sigrist, C., Faulstich De Paiva, J. M., Oliveira Nunes, A., & Da Silva Moris, V. A. (2017). A study on the environmental aspects of WEEE plastic recycling in a Brazilian company. The International Journal of Life Cycle Assessment, 22(12), 1957–1968. https://doi.org/10.1007/s11367-017-1282-2

Mohammed, M. I., Wilson, D., Gomez-Kervin, E., Tang, B., & Wang, J. (2019). Investigation of Closed-Loop Manufacturing with Acrylonitrile Butadiene Styrene over Multiple Generations Using Additive Manufacturing. ACS Sustainable Chemistry & Engineering, 7(16), 13955–13969. https://doi.org/10.1021/acssuschemeng.9b02368

Mohammed, M., Wilson, D., Gomez-Kervin, E., Petsiuk, A., Dick, R., & Pearce, J. M. (2022). Sustainability and feasibility assessment of distributed E-waste recycling using additive manufacturing in a Bi-continental context. Additive Manufacturing, 50, 102548. https://doi.org/10.1016/j.addma.2021.102548

Obiadi, B. (2020). The Positive Impact of Plastic Recycling in the Built Environment.

OECD. (2022). Global Plastics Outlook: Policy Scenarios to 2060. OECD. https://doi.org/10.1787/aa1edf33-en
Optimization of Location-Routing for the Waste Household Appliances Recycling Logistics under the Uncertain Condition. (2022). Tehnicki Vjesnik - Technical Gazette, 29(1). https://doi.org/10.17559/TV-20210623085943
Pelto, J., Barreto, C., Anwar, H., Strobl, L., & Schlummer, M. (2023). Compatibilized PC/ABS blends from solvent recycled PC and ABS polymers from electronic equipment waste. Polymer Testing, 120, 107969. https://doi.org/10.1016/j.polymertesting.2023.107969

Peters, S. (2011). Material Revolution Sustainable and Multi-Purpose Materials for Design and Architecture.

Plastics Europe. (2022). The Circular Economy for Plastics, A European Overview.

Ragaert, K., Delva, L., & Van Geem, K. (2017). Mechanical and chemical recycling of solid plastic waste. Waste Management, 69, 24–58. https://doi.org/10.1016/j.wasman.2017.07.044

Ragaert, K., Huysveld, S., Vyncke, G., Hubo, S., Veelaert, L., Dewulf, J., & Du Bois, E. (2020). Design from recycling: A complex mixed plastic waste case study. Resources, Conservation and Recycling, 155, 104646. https://doi.org/10.1016/j.resconrec.2019.104646

Ror, C. K., Negi, S., & Mishra, V. (2023). Development and characterization of sustainable 3D printing filaments using post-consumer recycled PET: Processing and characterization. Journal of Polymer Research, 30(9), 350. https://doi.org/10.1007/s10965-023-03742-2

Sadeghi, B., Marfavi, Y., AliAkbari, R., Kowsari, E., Borbor Ajdari, F., & Ramakrishna, S. (2021). Recent Studies on Recycled PET Fibers: Production and Applications: a Review. Materials Circular Economy, 3(1), 4. https://doi.org/10.1007/s42824-020-00014-y

Schwarz, A. E., Ligthart, T. N., Godoi Bizarro, D., De Wild, P., Vreugdenhil, B., & Van Harmelen, T. (2021). Plastic recycling in a circular economy; determining environmental performance through an LCA matrix model approach. Waste Management, 121, 331–342. https://doi.org/10.1016/j.wasman.2020.12.020

Serranti, S., Gargiulo, A., & Bonifazi, G. (2012). Classification of polyolefins from building and construction waste using NIR hyperspectral imaging system. Resources, Conservation and Recycling, 61, 52–58. https://doi.org/10.1016/j.resconrec.2012.01.007

Singh, P., Katiyar, P., & Singh, H. (2023). Impact of compatibilization on polypropylene (PP) and acrylonitrile butadiene styrene (ABS) blend: A review. Materials Today: Proceedings, 78, 189–197. https://doi.org/10.1016/j.matpr.2023.01.350

Soni, A., & Das, P. K. (2022). Development of sand-plastic composites as floor tiles using silica sand and recycled thermoplastics mixture from post-consumer products—A sustainable approach for cleaner production. https://doi.org/10.21203/rs.3.rs-1376161/v1

Sorensen, J. (n.d.). Ecological Rucksack for materials used in everyday products.
Stallkamp, C., Volk, R., & Schultmann, F. (2022). The impact of secondary materials' quality on assessing plastic recycling technologies. E3S Web of Conferences, 349, 05001. https://doi.org/10.1051/e3sconf/202234905001

Subhani, H. A., Khushnood, R. A., & Shakeel, S. (2024). Synthesis of recycled bricks containing mixed plastic waste and foundry sand: Physico-mechanical investigation. Construction and Building Materials, 416, 135197. https://doi.org/10.1016/j.conbuildmat.2024.135197

Thirumaran, K., Balaji, G., & Prasad, N. D. (Eds.). (2021). Sustainable Urban Architecture: Select Proceedings of VALUE 2020 (Vol. 114). Springer Singapore. https://doi.org/10.1007/978-981-15-9585-1

Thomas, A., Baah, C. K., Odonkoh, J., & Offei, S. W. (2023). Investigation of Recycled Plastic Waste into Bricks for the Construction of Housing Projects in Ghana. Journal of Engineering Research and Reports, 25(8), 107–114. https://doi.org/10.9734/jerr/2023/v25i8963

Vidakis, N., Petousis, M., & Maniadi, A. (2021). Sustainable Additive Manufacturing: Mechanical Response of High-Density Polyethylene over Multiple Recycling Processes. Recycling, 6(1), 4. https://doi.org/10.3390/recycling6010004

Vollmer, I., Jenks, M. J. F., Roelands, M. C. P., White, R. J., Van Harmelen, T., De Wild, P., Van Der Laan, G. P., Meirer, F., Keurentjes, J. T. F., & Weckhuysen, B. M. (2020). Beyond Mechanical Recycling: Giving New Life to Plastic Waste. Angewandte Chemie International Edition, 59(36), 15402–15423. https://doi.org/10.1002/anie.201915651

Wang, D. H. (n.d.). Extrachromosomal DNA appears before cancer.

Wei, T., Zhou, P., Liu, W., Liu, X., & Kuang, T. (2024). Catalytic recycling of plastics into value-added products. Nano Research, 17(11), 9428–9445. https://doi.org/10.1007/s12274-024-6955-0

Wijngaard, M., Dortmans, A., Harmelen, T. V., Urbanus, J. H., Ruiter, R. D., Schwarz, A., & Zondervan, E. (2020). SOLVING THE DARK SIDE OF TODAY'S PLASTIC.

Yuan, P. F., Chai, H., Yan, C., Li, K., & Sun, T. (Eds.). (2023). Hybrid Intelligence: Proceedings of the 4th International Conference on Computational Design and Robotic Fabrication (CDRF 2022). Springer Nature Singapore. https://doi.org/10.1007/978-981-19-8637-6

Zhang, J., Hirschberg, V., & Rodrigue, D. (2022). Mechanical fatigue of recycled and virgin high-/low-density polyethylene. Journal of Applied Polymer Science, 140(2).

Zhang, O., Takaffoli, M., Ertz, M., & Addar, W. (2023). Environmental Impact Assessment of Plastic Waste Management Scenarios in the Canadian Context. Environments, 10(12), 213. https://doi.org/10.3390/environments10120213

Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

   The core of the thesis is centred around innovation-driven material research and building product innovation with an emphasis on research-by-design and design for recycling approaches. The material testing, laboratory work and structural validation fall within the scope of Building Technology. Whereas the focus on practical implementation of the selected design in the built environment and attention to circularity strategies align with the goals of the Architecture faculty, Moreover the design proposal addressing societal, industrial and scientific challenges related to sustainability, waste management and innovation in construction materials aligns with the goals as well. The integration of the processing technique of injection molding with product design that takes its foundation points from the material research done on recycling residues rather than virgin materials represents a novel convergence between structural design and building product innovation.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework?

The thesis focuses on social, professional and scientific fields during each phase of the study:

Social Relevance:

- The thesis tackles the growing accumulation of plastic waste, contributing to environmental pollution and public health challenges. With the expected tripling of global plastic use by 2060, the work offers a sustainable alternative to reducing waste accumulation (OECD, 2022).
- By exploring the potential of unrecycled plastic waste for architectural components, the work reduces the reliance on incineration and landfilling. This aligns with future CO2 emission mitigation goals (Vollmer et al., 2020).
- The work contributes to the circular economy by reintegrating unrecycled plastic waste into the material cycle. This effort aligns with EU policies like the Green Deal and Circular Economy Action Plan, which aim to increase the use of recycled plastic materials by reducing the reliance on virgin plastics (Wijngaard et al., 2020).

Professional Relevance:

- As the construction industry is the second-largest consumer of plastics, the work provides an alternative to integrating recycled plastics into architectural components, addressing the industry's needs and standards.
- The work aligns with Design for Recycling, which envisions material recovery and reuse at the end of the product’s life cycle.
- By developing a recipe for open-loop mechanical recycling with the unrecycled fraction of recycling practices, the work creates an alternative manufacturing process to conventional production methods.

Scientific Relevance:

- The thesis explores open-loop mechanical recycling for mixed and contaminated plastics while addressing the scientific gaps in polymer blending and compatibility.
- The experimentation phase concludes with structural and thermal data to understand the applicability of recycled plastics for high-value applications.
- The proposed methodology offers scalable end-products for the construction industry, which opens the possibility for further studies in other industries, such as automotive and packaging.