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	Rhea Ishani
Student number	5315883

Studio		
Name / Theme	Building Technology Graduation Studio/ Façade & Products	
Main mentor	Dr.-Ing Tillmann Klein	AE+T | Building Product Innovation
Second mentor	Dr. Michela Turrin	AE+T | Design Informatics
Argumentation of choice of the studio	N/A	

Graduation project	
Title of the graduation project	Remanufacturing for the Building Industry – Enabling the process through development of decision-making platform
Goal	
Location:	Delft, The Netherlands
The posed problem,	The building industry is material intensive and has significant impact on the economy and environment. It is responsible for approximately 40% of the total waste generated across the European Union (Boorsma et al., 2019). At the moment, the industry operates on the principles of the linear economy. However, because the linear economy is based on 'take-make-dispose' model, key issues such as resource scarcity, waste generation, and environmental pressure occur. By 2050, the Dutch Government aims to transition to Circular Economy and organize the building industry in a way to ensure sustainable construction by use, reuse, maintenance and dismantling of objects. (Netherlands Enterprise Agency, 2019) Remanufacturing is a strategy of the circular economy that supports this approach. It is a process of returning a used product to its original performance with a warranty that is equivalent to or better than that of newly manufactured product. It is an important component of resource efficient manufacturing as it reduces the dependency on virgin materials. Additionally keeping the components, for long life cycles leads to restoring the embodied material in use for longer, significant

	energy use, and emissions can be avoided. According to (Stahel, 2016) smaller the loop (technical cycle), the more profitable it is. (Macarthur, n.d.) further, describes the power of smaller loop in terms of greater savings with respect to embedded costs in terms of labor, energy, capital, and external factors (GHG emissions). The integration of digital platform and support systems in other industries are considered as important drivers of remanufacturing. They have proved to enable remanufacturing by enabling design upgradability to ensure market adaptability and enriching customer relationships. Remanufacturing is more valuable than recycling as it protects the complete shape of the product. This closed loop product extension; lower impact approach fits within the frame of Circular Economy. Circular economy is not an end goal but a means to introduce sustainable practices. However, despite all the advantages of remanufacturing, it has not been applied in the building industry on a large scale. This is unfortunate considering building products are mass-produced and standardized. Buildings contain large volumes at products, made of high value materials available at fixed locations. This is because the design activity of building products is centered around single use. Moreover, building products are not standalone entities but and are always integrated with other assemblies. The ownership period is shorter than the life of the product, which makes it difficult to retrieve them at EOL. Furthermore, it is a dynamic and fragmented industry that involves many stakeholders during the decision-making process. As mentioned before, the integration of digital platforms and support systems in other industries have contributed to the success of remanufacturing. However, an approach to digital platform and support system for Design for remanufacturing (DfRem) in the industry is still missing. To begin with the focus is on developing a conceptual framework to discuss the potential of remanufacturing (reman) in the building industry. Second is to redesign parts, components of the building product to enable reman over its life cycle. Third is to develop a decision-making platform to guide the evolution in design and circulation (collection of cores) of the product.
research questions and	The main objective of this research project is to evaluate the function, characteristics, and performance of a building product in the context of circular economy and contribute in two ways; one to redesign to enable remanufacturing (reman) and two to develop a decision-making platform to assist reman other following product life extension strategies. Thus, the main research question formulated is:

	"Which building product can be redesigned to allow remanufacturing over its lifecycle, by utilizing a decision-making platform to streamline the process?" From which the following research questions arise: 1. What is remanufacturing, and how is it different from the other 're' strategies of the circular economy? 2. What are the conditions and criteria for successful remanufacturing and how can these be applied to the building industry? 3. What characteristics and parameters must be integrated in an A-Product to allow remanufacturing over its life cycle? 4. What are the available guidelines, drivers, and barriers for the remanufacturing of A-Products? 5. What is the current EOL scenarios for an A-Product and what 're' strategies can be implemented to extend their life cycle? 6. How can the decision-making platform assist in streamlining the process of remanufacturing at the product level? 7. What is the role of architects and designers to enable and promote products to be designed for remanufacturing?
design assignment in which these result.	The research will lead to the redesign of parts, components of a building product for scenarios of remanufacturing and other 're' strategies over its entire life cycle, followed by the construction of a digital remanufacturing platform, to support the evolution in design and circulation (collection of cores at EOL) of a product. Thus, the design question formulated is, "How can parts, elements and connections of a product be redesigned to allow for remanufacturing to extend its over its lifecycle?"
Process	
Method description	
The problem statement throws light on the situation that there is no existing example of remanufacturing process of building products being conducted on a large scale. Therefore, the program's methodology consists of finding the research gap through **literature study and data Review**, which will assist in developing a conceptual framework to guide remanufacturing of Building Products. This step is followed by **design and analysis** guided by the previously developed framework. After design, the focus is on developing guidelines for **manufacturing and assembly**. This is	

followed by the last step, which is **evaluation** of the entire process and reflection on the solutions obtained at the end of the process.

Phase 1: Literature Study & Data Review

The state-of-the-art literature reviews are conducted to understand remanufacturing as a strategy through definitions and theories. To get a perspective on current scenarios, 20 successful examples of remanufacturing were listed, and a product canvas is made. As a next step five examples that match the complexities to building products are chosen to analyze the product *parameters, criteria and conditions* that make the remanufacturing process successful. The Analysis procedure outlines barriers, drivers, market demand, value proposition, revenue streams, supply, and logistics to outline key challenges and related solutions faced by each company. Additionally, a SWOT analysis is done to first understand the role of digitalization process in remanufacturing and to assist the development of a conceptual framework to understand the interventions in the product life cycle (PLC). The analysis from case studies stands as validation of theories and concepts gathered from papers. The standard search terms for Circular Building products and remanufacturing included: 'Eco design', 'Digitalization for Circular Economy', The research material also included previous thesis reports, Ph.D. results, Journals, and reports from European Remanufacturing Network, r2pi projects. The search results were organized into groups of Remanufacturing: as a strategy, Circular Economy, Remanufacturing in other industries, Digitalization in CE, Circular Building Products.

Phase 2: Design and Analysis

The Design and Analysis is divided into Research and Design phase. The previous phase ends with the development of a conceptual framework that can guide remanufacturing in the Building Industry. This is then discussed with experts in the field to receive feedback and assist in selection of a building product. This step is followed by conducting interviews with experts and professionals from the company to understand the engineering guidelines, design criteria and limitations. The interviews are designed to receive feedback on the redesign concept. An inductive method is adopted to study the drawings, CAD models, to develop a deeper understanding of the product. At the end of this phase, the motivation is to redesign a product, by presenting preliminary and detail design of parts & components.

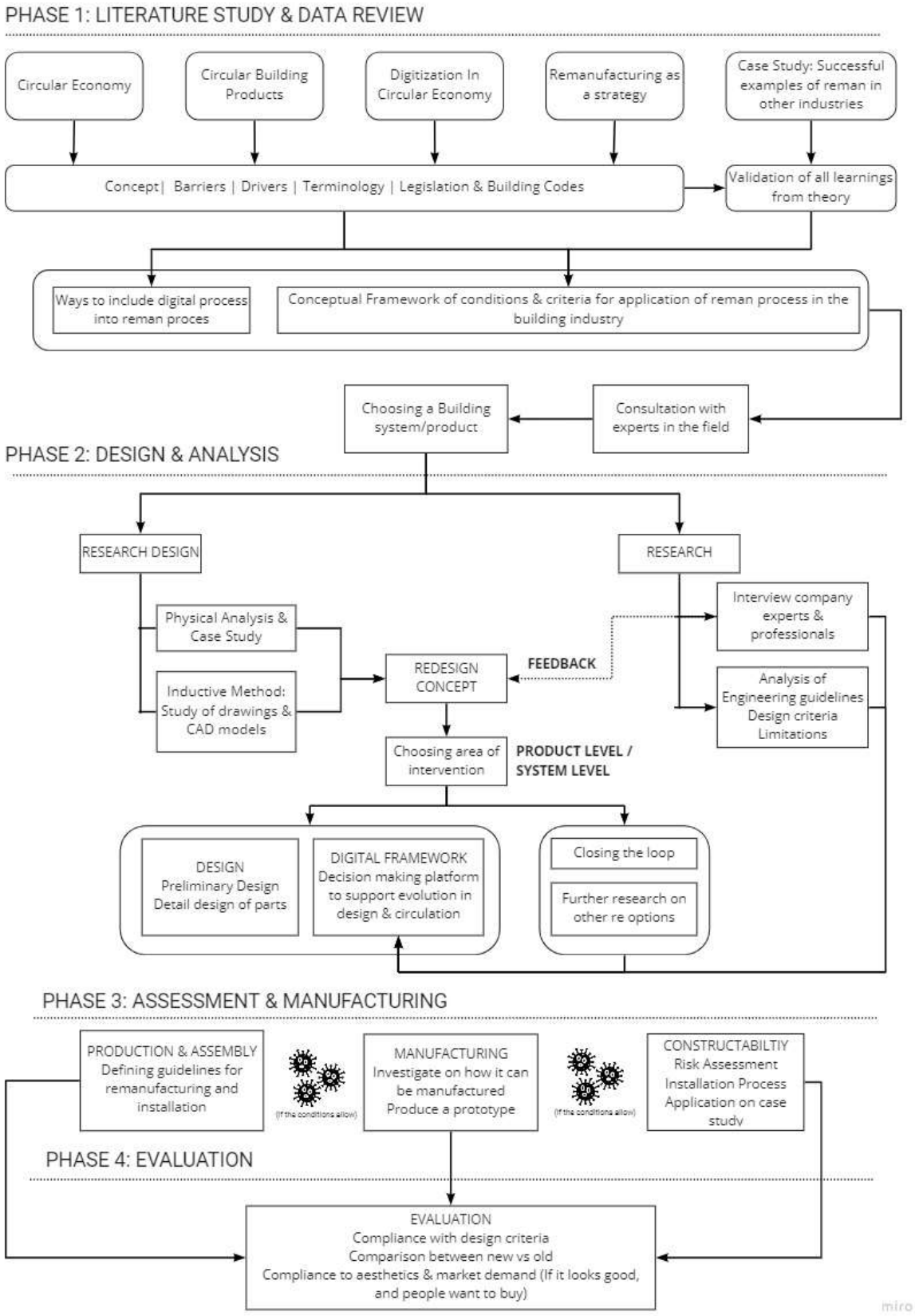
Development of a Remanufacturing design Platform

After the redesign phase, the focus is on creating a decision-making platform with a goal to assist the manufacturer to assess the remanufacturability and future life efficiency of an EOL product. The platform is a collection of the design criteria (gathered from company experts), results of embodied carbon, Life Cycle Analysis. The project will indulge in forecasting the material recovery of the product at EOL by doing a Life Cycle Analysis (LCA), to calculate the embodied carbon at component and product level. Once the current condition of a product is examined, the manufacturer can decide the "re" strategy for every component of the product. The Author will dedicate time to show at least some parts of the platform as a proof of concept. As a result, the platform will support the evolution in design and circulation of the product.

Phase 3: Assessment & Manufacturing
After redesigning the product, and the product platform this phase of the project will involve focusing on three sub phases – production and assembly, manufacturing, and constructability. At this stage of the project, the steps mentioned are desirable to work on and will be elaborated in the next phases depending on feasibility in terms of time, and working condition with the ongoing pandemic

Phase 4: Evaluation
The research and design findings will be summarized by checking the compliance with the design criteria, structural & thermal rules, aesthetics and market demand, and a detail comparison between the new vs old will be made. The results will be summarized in a tabular format and charts. In some cases, the results from softwares can help in validation of redesign concept. Conceptual flowcharts will be made to describe specific computational platforms, to showcase the intended functionality of the same.

The Phase 1 will answer the research questions 1,2 & 3 and lay a conceptual framework for design. Phase 2 is focused on answering the research questions 4, 5 & 6 at a product level. The Phase 3 & 4 will validate the answers to all the research questions and highlight the role of architects and designers in the process of promoting remanufacturing as a strategy as a concluding remark. The figure gives a thematic organization of the research methodology.


PHASE 1: LITERATURE STUDY & DATA REVIEW
Circular Economy
Circular Building Products
Digitization In Circular Economy
Remanufacturing as a strategy
Case Study: Successful examples of reman in other industries
Concept| Barriers | Drivers | Terminology | Legislation & Building Codes
Validation of all learnings from theory
Ways to include digital process into reman proces
Conceptual Framework of conditions & criteria for application of reman process in the building industry
Choosing a Building system/product
Consultation with experts in the field
PHASE 2: DESIGN & ANALYSIS
RESEARCH DESIGN
RESEARCH
Physical Analysis & Case Study
Inductive Method: Study of drawings & CAD models
REDESIGN CONCEPT
FEEDBACK
Interview company experts & professionals
Analysis of Engineering guidelines Design criteria Limitations
Choosing area of intervention
PRODUCT LEVEL / SYSTEM LEVEL
DESIGN
Preliminary Design
Detail design of parts
DIGITAL FRAMEWORK
Decision making platform to support evolution in design & circulation
Closing the loop
Further research on other re options
PHASE 3: ASSESSMENT & MANUFACTURING
PRODUCTION & ASSEMBLY
Defining guidelines for remanufacturing and installation
(If the conditions allow)
MANUFACTURING
Investigate on how it can be manufactured
Produce a prototype
(If the conditions allow)
CONSTRUCTABILTIY
Risk Assessment
Installation Process
Application on case study
PHASE 4: EVALUATION
EVALUATION
Compliance with design criteria
Comparison between new vs old
Compliance to aesthetics & market demand (If it looks good, and people want to buy)
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Literature and general practical preference

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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)?

   Relation between graduation project and master track

   The façade and products graduation studio aims for innovative technologies that point towards closing material loops and in the direction of circular economy in the built environment. Remanufacturing is explored as a strategy to extend the life cycle of products. The successful examples from the other industries such as automobile, electrical hint resource and material efficiency. The fact that building products are standardized gives it a bigger chance to make reman successful. The building industry has always been the last one to apply new technologies due to problems with large number of stakeholders and the life cycle of a building itself, that poses challenges. The aim of the research project is to develop a conceptual framework and to redesign the product and construct a platform to support the evolution in design and circulation. This is an innovation approach, as it has not been adopted before and gives the chance to make an intervention at the product level and the system level. It is valuable as at the end of its evaluation, it can serve as a framework towards guiding remanufacturing of other products. The focus is on Façade and Products, and Design Informatics as it indulges in developing a decision-making support system, so it is safe to say that the project spans two sub directions under the Building Technology Track.

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

   Social relevance

As every country climbs up the material ladder, there is a growing demand for new materials and products. As resource scarcity, waste management and climate change are the issues we are trying to protect ourselves from. The concern is not so much that there isn't any left, but that it may be difficult to upscale the production capacity quickly enough. There is a frantic search ongoing for new sources of materials, not just in the ground but also in deep seas and even in space. As our energy system is based on fossil fuels, the use of energy leads to massive amounts of CO2 emissions. In as far as the energy is used to produce resources, these CO2 emissions may be attributed to the resources themselves. These challenges are the main reason to go for a circular economy, and that is what we must keep in mind whenever we assess specific and concrete options for improved circularity. The market demands change swiftly, and adaptive remanufacturing serves as a strategy for two reasons, first being that it is a smaller loop than recycling (which is more common than reman) and secondly it ensures economic viability and resource efficiency. Remanufacturing returns the product to "as new" or even better condition with a comparable warranty to the original product. Through case studies we have seen that

construction of a reman design platform ensures successful implementation of reverse logistic channels, creation of a value network and gives the opportunity to offer customers upgrades that can match with the growing needs. The project focuses on going a full circle, from exploring potential of remanufacturing for the building industry to application of methods to make it successful, thereby highlighting the social relevance of the project.

Professional relevance

To ensure sustainability and change the traditional "take-make-dispose" model, modern manufacturing should consider resource scarcity, supply chain management, and energy costs. A report on 'A Circular Economy in the Netherlands by 2050' emphasizes that the vision for the construction industry is to be organized in a way that the design, development, operation, management, and disassembly of buildings are respected to ensure sustainable construction, use, reuse, maintenance, and dismantling of objects. From case studies, we know that smaller loops are more profitable than larger, which in essence means that in most cases, remanufacturing can be a better strategy for material efficiency and resource recovery than recycling. This makes the topic relevant at a professional level.

Several companies in the Netherlands and abroad (MADASTER, Circular Cloud, New Horizon) are developing various methods, strategies, and roadmaps to integrate digital technologies to implement a Circular Economy. However, a majority of them address problems at the building scale. The project aims to focus on a building system or a product level to intervene and bring in circular choices that can change the way they perform and can be recovered at EOL to be reused again.

Scientific relevance

The topic finds itself under the broad realm of Circular Economy and aims to explore the potential of remanufacturing for the building industry. A building, rather than being viewed as a single product, should be viewed as a collection of products. According to a study on Lifecycle stages and modules by Orr, Gibbons, and Arnold (2020), the extraction, processing, manufacturing, and transport of materials up to the point where they leave the factory gate to be taken to site contribute to roughly half of the carbon emissions calculated throughout the lifecycle of a building. Buildings account for a significant portion of total energy consumption in European countries (42 percent) (Kanters, 2020). Modern manufacturing should consider resource scarcity, supply, and demand.

One attempt of transitioning to a circular economy is being done by TU Delft together with other stakeholders who are working on developing on a Product Service System for Façade Industry to bring in the concept of Extended Producer Responsibility (EPR). Building products have many similarities to remanufactured products from other industries in that they contain large volumes of products in fixed locations with high value materials, creating opportunities for remanufacturing. Due to a dynamic and fragmented market with multiple stakeholders involved in the decision-making process, the building industry has always

lagged in keeping up with emerging technologies. Other related industries (automotive, aerospace, and logistics, for example) have demonstrated successful integration of remanufacturing due to early adoption of these business practices. This project will serve as a conceptual framework to guide remanufacturing of building products.

Limitations of the Research project

1. A lot of information obtained on the chosen product may be treated as confidential. As a result, the project will focus on the data available through research, interviews, stakeholders, and mentors.
2. The conceptual framework developed at the initial phase of the project is treated to be operational at a nascent level. As this is developed because of limited amount of case study examples of successful remanufacturing practices in other industries.
3. The project focuses on a product level and so the area of intervention will be small and focused. It may be revised in the later stages of the project to match the feasibility and working conditions during the pandemic
4. The integration of digital methods is restricted to construction of a remanufacturing design platform that will support the evolution of design and circulation (collection of cores) of the product.
5. The project will dedicate time to work on proof of concept of at least some parts of the platform and for the others, the demonstrations will only be a visual representation with a high-level flowchart indicating the various processes since the entire platform cannot be developed in time.

Graduation timeline

		Calendar Week	Nov		December					January				Febraury				March					April				May					June					July
Task ID	Research Objective	Activity	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27	W28	W29	W30	W31	W32	W33	W34	W35
1	Literature Review & Data Review	Study on Circular Economy (CE) & Strategies of CE																																			
2		Circular Built Environment & Building Products																																			
3		Digitization in CE																																			
4		Remanufacturing as a strategy																																			
5		Case Study: 20 examples of reman in other industries																																			
6		Ways to inculde digital methods, role of ICT																																			
7		Conceptual framework of reman for building Industry																																			
8	Design and Ananlysis	Choosing an A-Product																																			
9		Study on the chosen A-Product																																			
10		Analysis of Design criteria, guidelines, legislation																																			
11		Inductive method																																			
12		Company/Stakeholder interviews																																			
13		Redesigning parts and components																																			
14		Development of decision-making platform																																			
15		Further research to close the loop																																			
16	Assessment & Manufacturing	Production and Assembly																																			
17		Manufacturing																																			
18		Constructability																																			
19	Evaluation and reflection	Evaluation																																			
20		Report																																			
21		Presentation																																			

The grey boxes indicate desired steps, which will be taken if time and working conditions with the ongoing pandemic permit them.