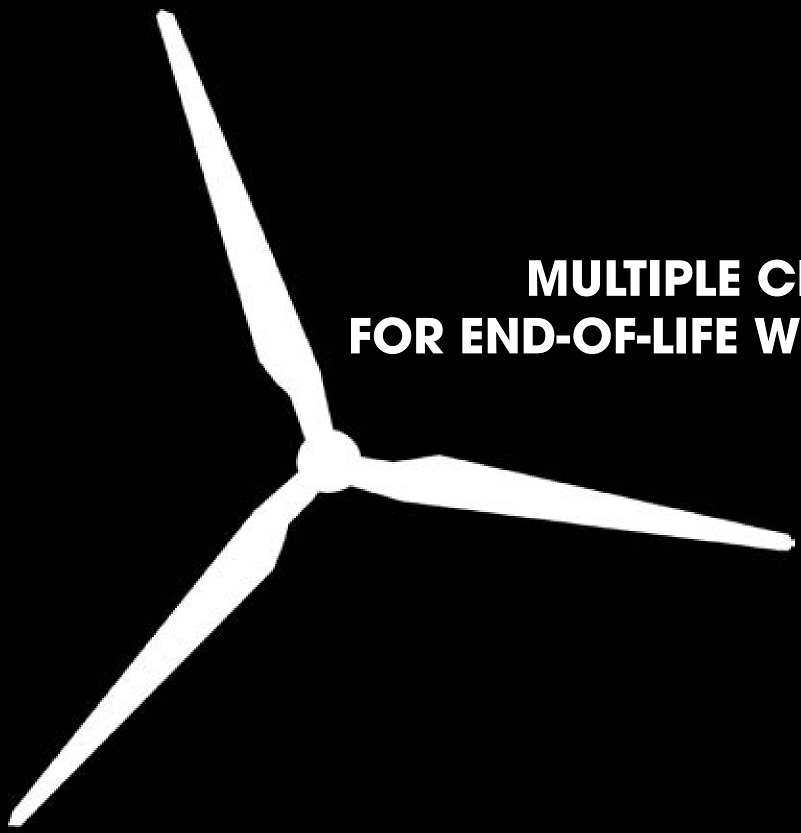

MULTIPLE CIRCULAR STRATEGIES FOR END-OF-LIFE WIND TURBINE BLADES

Nguyen Binh Minh
Architectural Engineering studio
Delft University of Technology

Figure 1.1 Fragments of wind turbine blades await burial at the Casper Regional Landfill in Wyoming.
Source: Benjamin Rasmussen

AUTHOR, MENTORS & STUDIO

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Argumentations of choice of the studio:

- *Practical approach with advanced technical background*
- *Independence of investigating topics and locations*
- *Tutors with specific experience regarding the chosen topic (wind turbine blades)*
- *High recommendation from former students (Coen de Vries)*

** Minh is the First name, Nguyen is the Last name*

MULTIPLE CIRCULAR STRATEGIES FOR END-OF-LIFE WIND TURBINE BLADES

KEYWORDS

Wind farm, wind turbine blade, circular strategy, circularity, reuse, refuse, recycle, repurpose

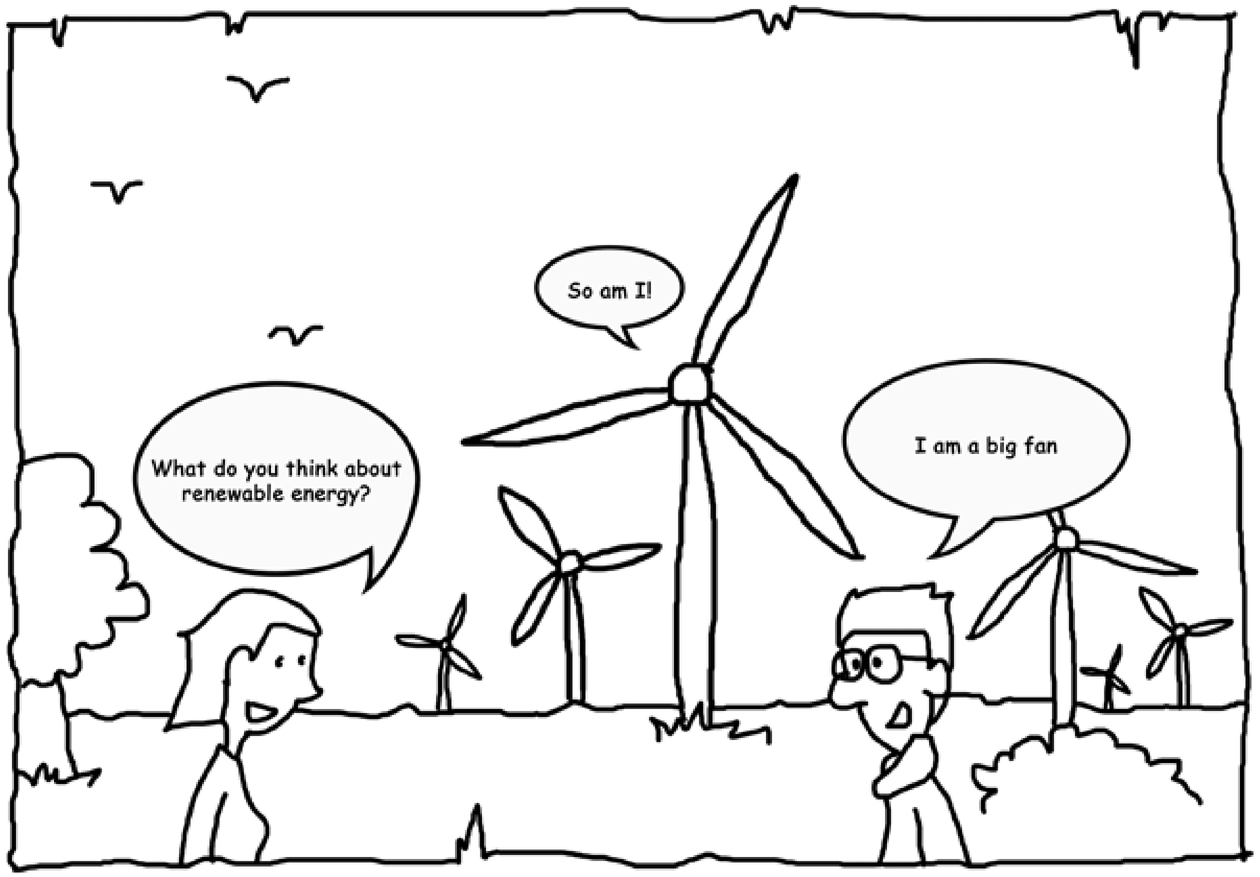

Figure 1.2: Graphic of wind turbine blades - own image

PROBLEM STATEMENT
The negative side of the Wind power industry

WIND ENERGY - A KEY ROLE TO TACKLE CLIMATE CHANGE

Mankind's current annual use of natural resources and its generation of waste and emissions actually requires approximately 1.75 Earths (Global Footprint Network). A major driving force in this is our petroleum energy system, which relies on the consumption of a limited resource and is a major contributor to greenhouse gas emissions and the advancement of climate change (Scheepens, 2021).

To forestall cataclysmic climate change brought about by consuming petroleum derivatives, numerous governments and companies have sworn to utilize only clean energy by 2050 (Jani et al., 2022). One of the most cost-effective ways to achieve that goal is wind energy, as an incredibly important asset to the global energy transition (Scheepens, 2021).

The implementation of wind power plays a central role in the Netherlands. They aim to achieve a decrease in CO2 emissions of 49% by 2030 and of 95% by 2050 compared to 1990 levels (Rijksoverheid, nd), and the wind is to become the leading electricity producer by 2050 (PBL, 2017). According to Rob Jetten, the Minister of Climate and Energy of the Netherlands, after the refusal to import gas and coal from Russia in 2022, they have been aiming to move towards sustainable energy sources such as offshore wind power.

43 MILLION TONS OF WASTE FROM THE WIND POWER INDUSTRY

Due to the ever-rising growth of wind power, end-of-life (EoL) wastes from the wind turbine blades (WTB) are one of the major environmental problems. Approximately 43 million tons of blade waste are projected to enter the stream by 2050, the vast majority of which is comprised of glass fiber-reinforced polymer. (Glosser et al., 2022).

One of the main reasons is the fast development of the global wind industry, in terms of both the number of turbines and their sizes (Larsen, 2019). According to the Global Wind Energy Council, modern turbines are 100 times the size of those in 1980. A further implication of this is the fact that blades are becoming ever-larger, now reaching dimensions similar to Boeing 747 airplanes (Martin, 2020). After 20-25 years, those old blades have been replaced by new blades which are larger and more financially productive. When compared to the smaller blade, the larger one can capture more energy, resulting in much better efficiency (Jani et al., 2022).

Another factor contributing to the enormous amount of waste is the composition of WTB, which has been made from polymer composite reinforced with mainly glass fiber, some carbon fiber, and a hybrid combination of them (Liu and Barlow, 2017). These materials brought a high strength-to-weight ratio and rigidity to WTB (Jani et al., 2022), which made them strong in order to withstand high wind speeds, at the same time be as light as possible in order to reach higher efficiencies (Scheepens, 2021). Complex composite material structures allow for such a design, yet are difficult to recycle (Yang et al., 2012).

The lack of viable recycling options meant that a large number of WTB has been being landfilled or incinerated (Schmid et al., 2020; van der Meulen et al., 2020). Worth mentioning is the turbine landfill in Casper, which was humongous that it can be seen from space, as in satellite images (from Figure 2 to Figure 7). These are the least preferred solution in terms of the circular economy (Scheepens, 2021). In response to this situation, many countries are now increasing landfill taxes (Rahimizadeh et al., 2019). In the Netherlands, landfilling of composites is officially forbidden (Scheepens, 2021). These rigorous restrictions intended to drive the industry seek potential resolutions.

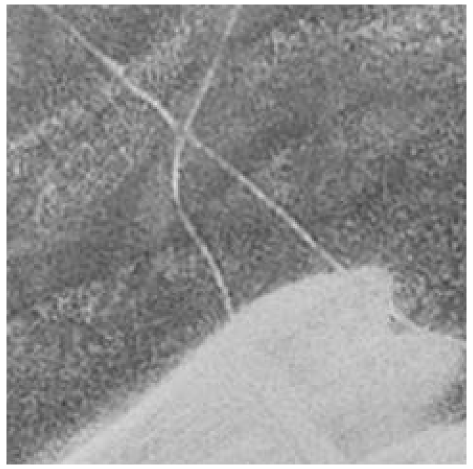

Figure 2.1: The Casper region in 1994
Photo's source: Google Earth

Figure 2.2: The Casper region in 2006
Photo's source: Google Earth

Figure 2.3: The Casper region in 2012
Photo's source: Google Earth

Figure 2.4: The Casper region in 2019
Photo's source: Google Earth

Figure 2.5: The Casper region in 2021
Photo's source: Google Earth

Figure 2.6: The Casper region in 2022
Photo's source: Google Earth

EFFORTS TO RESOLVE END-OF-LIFE WIND TURBINE BLADES IN RESEARCH

As aiming towards fully circular energy by 2050, it is important to develop EoL treatment facilities for WTB in the Netherlands, which are centrally located for current and future installed wind power (Andersen et al., 2016).

For a broad view, in 2021, Lobregt and his colleagues established a circular strategies framework based on the processes required to develop a more circular wind industry. The framework illustrates numerous domains and timeframes on which the sector should concentrate its efforts (Figure 3.1).

Based on that, recently numerous research and practices have been done in order to bring the EoL WTB back to the market, namely reusing, repurposing, and recycling the blades (Scheepens, 2021).

In 2019 and 2022, there were a number of research groups from the University of West Attica in Greece, and the School of Technology in India that investigated different methods of recycling which are mechanical, thermal (pyrolysis and oxidation in fluidized bed), and chemical procedures. Their results can be applied to recovered products such as making new composites, glass-ceramic products, production of thermoelectric composites, etc. Another research that is worth mentioning is recycling WTB as a building's material, by Simon Pronk, from the Faculty of Civil Engineering in Delft. His method was based on mechanic solutions to extract valuable elements from a decommissioned blade for applications in construction. This research has shown that EoL WTB can become parts of a building, such as beams, wall elements, or floor cladding.

All of those techniques have demonstrated a great deal of promise for treating the EoL WTB in various domains. However, each method's effects on the economy and the environment still need to be investigated and evaluated. The evaluation's findings will enable us to take a comprehensive look and determine the appropriate circular strategy for the EoL WTB's final volume.

REPURPOSING END-OF-LIFE WIND TURBINE BLADES IN PRACTICES

Along with the aforementioned studies, a significant number of projects related to EoL WTB have lately been carried out in the Netherlands and some other countries. As can be seen in the Appendix, those projects aimed to transform the material into urban amenities (Figures 10.1-10.8), elements of buildings (Figures 11.1-11.2), agricultural facilities (Figure 11.3), furniture and other products (Figures 12.1-12.3).

Those projects showed that the recently realized projects have been related to urban furniture, such as playgrounds, bike parking, and walking bridges; or domestic products, such as chairs and tables. Other adaptations such as elements of buildings are still on paper. This is because of additional time and costs to test the structural ability of the material (ORE Catapult, 2021). Another reason is that building standardization is also made difficult due to the large variety of blades (Scheepens, 2021). However, other research showed the potential of these projects. Notably, the energy intensities for the production of conventional building materials are between 196-257 MJ/kg for aluminum, 110-210 MJ/kg for stainless steel, and 30-60 MJ/kg for steel (Olivieux et al., 2015). These numbers are significantly higher than the energy demand for mechanical repurposed WTB, which is reported at around 5 MJ/kg (ORE Catapult, 2021) for segmenting the blade into useful parts. More detailed data about this will be investigated in the research.

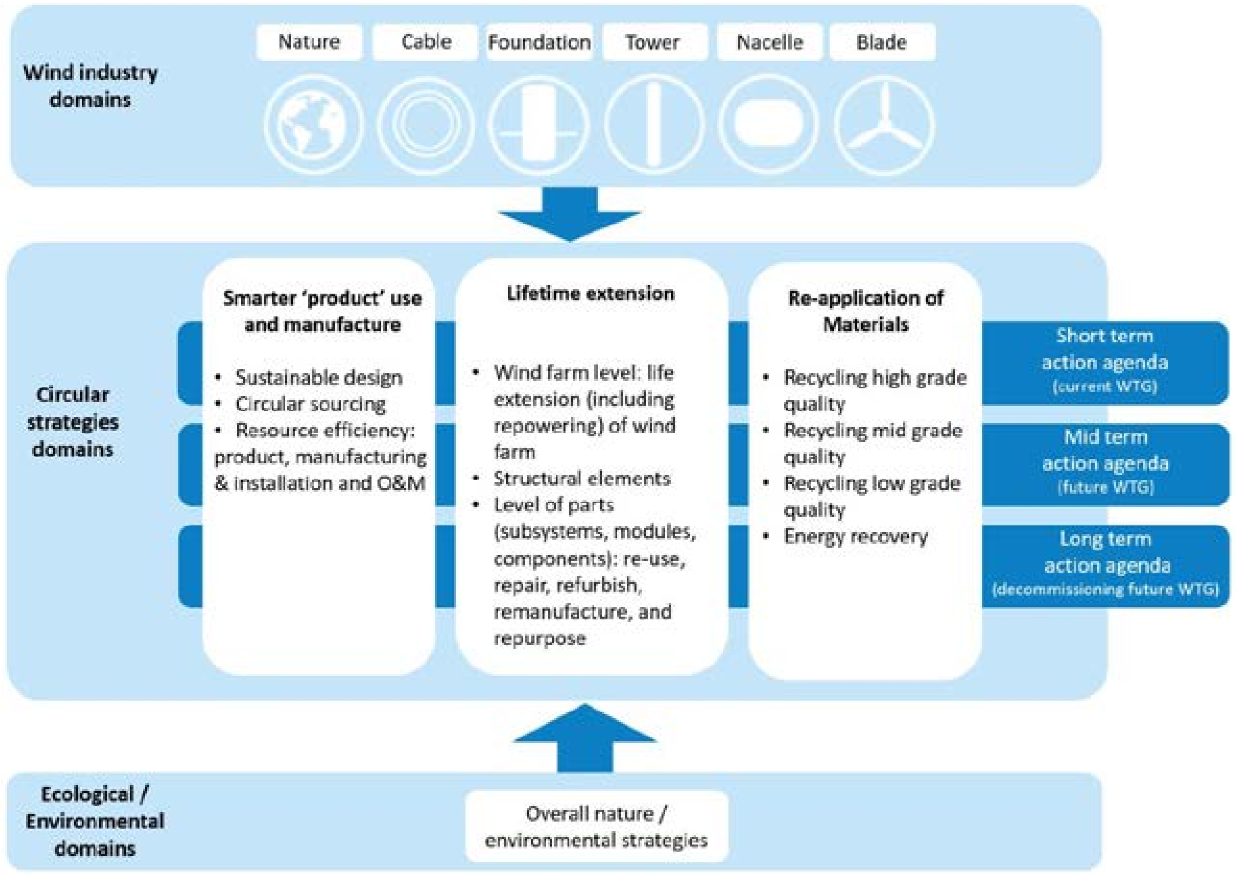

Figure 3.1: Circular strategies framework for the wind industry (Lobregt et al., 2021, p. 16)
Source: https://www.rijksoverheid.nl/documenten/rapporten/2021/04/16/ideation-process-focused-on-circular-strategies-in-the-wind-industry

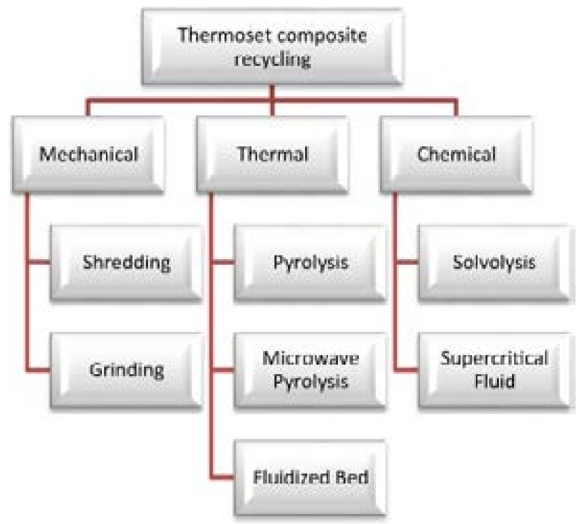

Figure 3.2: Categorization of the composite material recycling for WTB (Jani et al., 2022)
Source: https://www.sciencedirect.com/science/article/pii/S2214785322006125

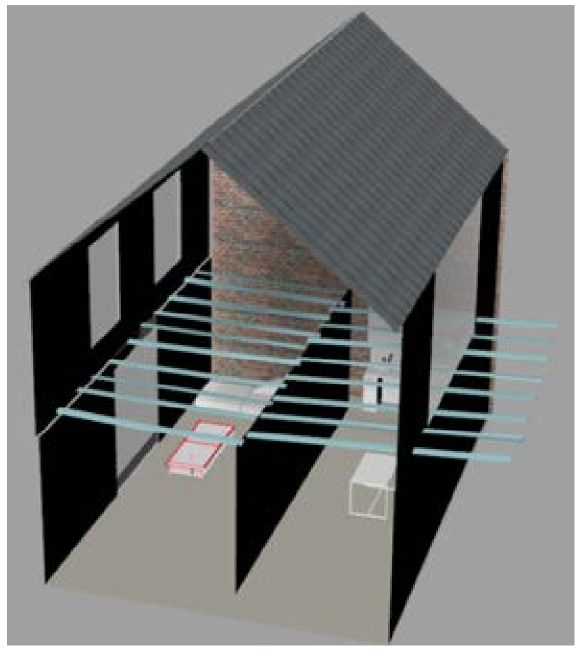

Figure 3.3: The resulting materials from wind turbine blades in structural beams (Pronk, 2022)
Source: http://resolver.tudelft.nl/uuid:d06683eb-3e99-44f7-992c-2040572301cb

PROBLEM STATEMENT

Eemshaven - the selected location for Wind turbine blades

WIND POWER IN EEMSHAVEN

Eemshaven has been known as a potential Energy Valley (Chen, 2011). Multiple factories and industrial facilities have been constructed since 1973.

Data from thewindpower.net in 2021 has shown that one of the areas with the most wind farms in the Netherlands is Eemshaven, which has Gemini with 150 turbines and Westereems with 69 turbines. Nearby are a number of additional wind farms with lower capacities, including GroWind, N33, Delfzijl-Noord, and Delfzijl-Zuid, which have 18, 15, 14, and 14 turbines, respectively. The broad image of wind farms in the Netherlands can be seen in Figure 4.1.

Eemshaven received investments from different wind power businesses, which resulted in a variety of WTB that can be seen there. According to data gathered from site visits and thewindpower.net, the region has a range of blade sizes that vary from 45 to 65 meters. Recycling or remanufacturing those large-sized blades requires a factory close to the wind farm in order to minimize transportation costs and other environmental effects. Multiple factories and industrial facilities of Eemshaven as mentioned above will be an advantage to adapting the circular method. This is one of the main reasons Eemshaven has been selected for the project

Accurate coordinates:	*Planned*	*Approved*	*Underconstruction*	*Operational*	*Dismantled*
Approximate coordinates:	*Planned*	*Approved*	*Underconstruction*	*Operational*	*Dismantled*

Figure 4.1: Wind farms in the Netherlands - own image
Data source: www.thewindpower.net

PROBLEM STATEMENT

Development plan and the current situation of Eemshaven

PROGRAMS & DEVELOPMENT PLAN

Programs of the project will be developed based on research about Eemshaven that has been done by X.Chen from the Faculty of Civil Engineering and Geosciences in Delft. It showed that the construction of Eemshaven as the Energy Valley is considered the most important development in the coming years. Two scenarios are set for different situations in Eemshaven.

The first scenario focuses on a future of 5-10 years, no large expansion is expected (Figure 5.1). The suggestions are developing energy-related industries and improving landside accessibilities. The second scenario foresees a significant port expansion of Eemshaven within the next 20–30 years (Figure 5.2). Industries more than energy are expected to form a cluster in the port area. Upgrading and having integrated plans such as agriculture-based industries (greenhouses, beverage products), recycling (energy, paper, plastic), etc.

Site visiting recently has shown another factor which is the significant number of tourists going to Eemshaven every weekend. The value of this trend including the number of tourists and their concern about the future of Energy Valley will be investigated and analyzed. Due to this fact, additional cultural and hospitality-related programs can be specifically adapted to Eemshaven.

CURRENT SITUATION IN EEMSHAVEN

Conflicts has appeared between villagers, developers, and the government in recent years, as Loek Mulder mentioned in rtvnoord.nl. According to developers and several businesses in Eemshaven, the development of the new part of this area, which will bring thousands of new jobs, is desperately needed. At the same time, data collected from the same website showed that villagers near Eemshaven are not supportive of that plan. They are worried about the environmental impacts and the natural landscape surrounding their villages. The government is suggesting to make smart combinations of economic development with ideas from residents for the quality of life, nature recreation, and sustainability.

The region surrounding Groningen, including Eemshaven, is experiencing earthquakes due to the extraction of gas. The municipality of Groningen has proposed a system of strategies to support citizens strengthening their houses, according to nationaalcoordinatorgroningen.nl. This will be an additional requirement during the research and design of the project.

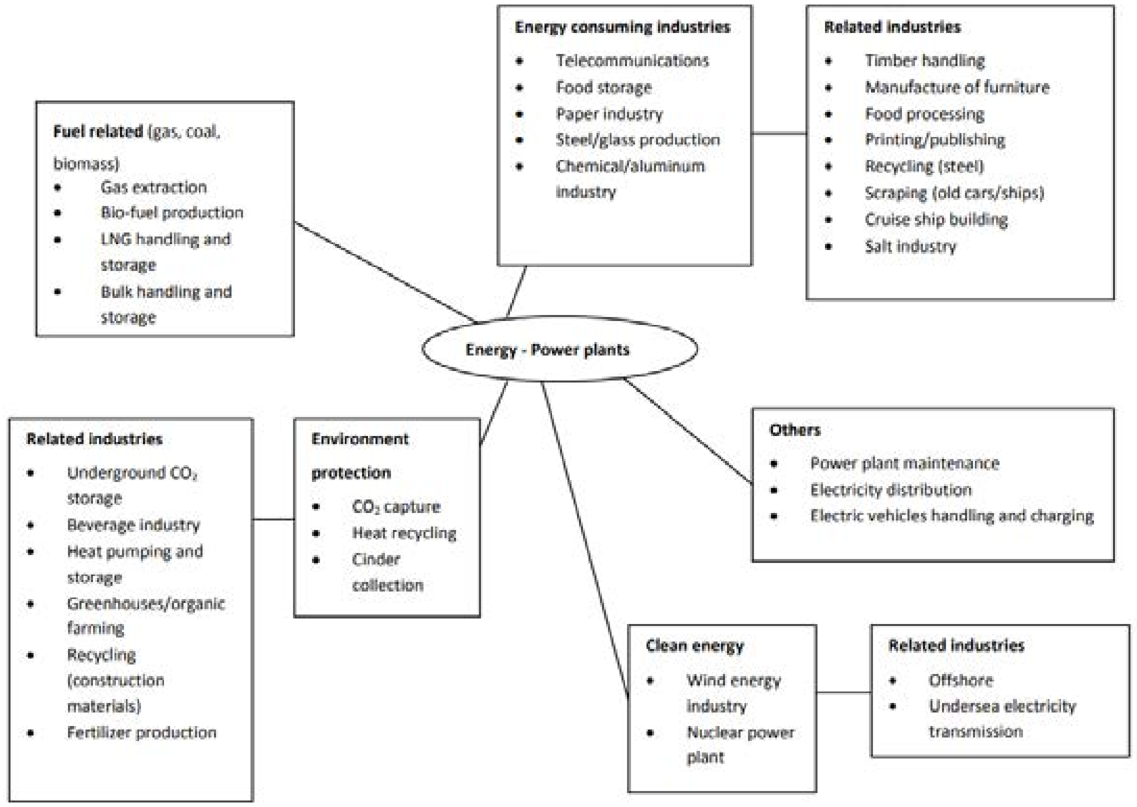

Figure 5.1: Development plan of Eemshaven - Programs for senario 1 (Chen, 2011)
Source: http://resolver.tudelft.nl/uuid:623bdcbc-d448-47da-8cf8-50725e600b1e

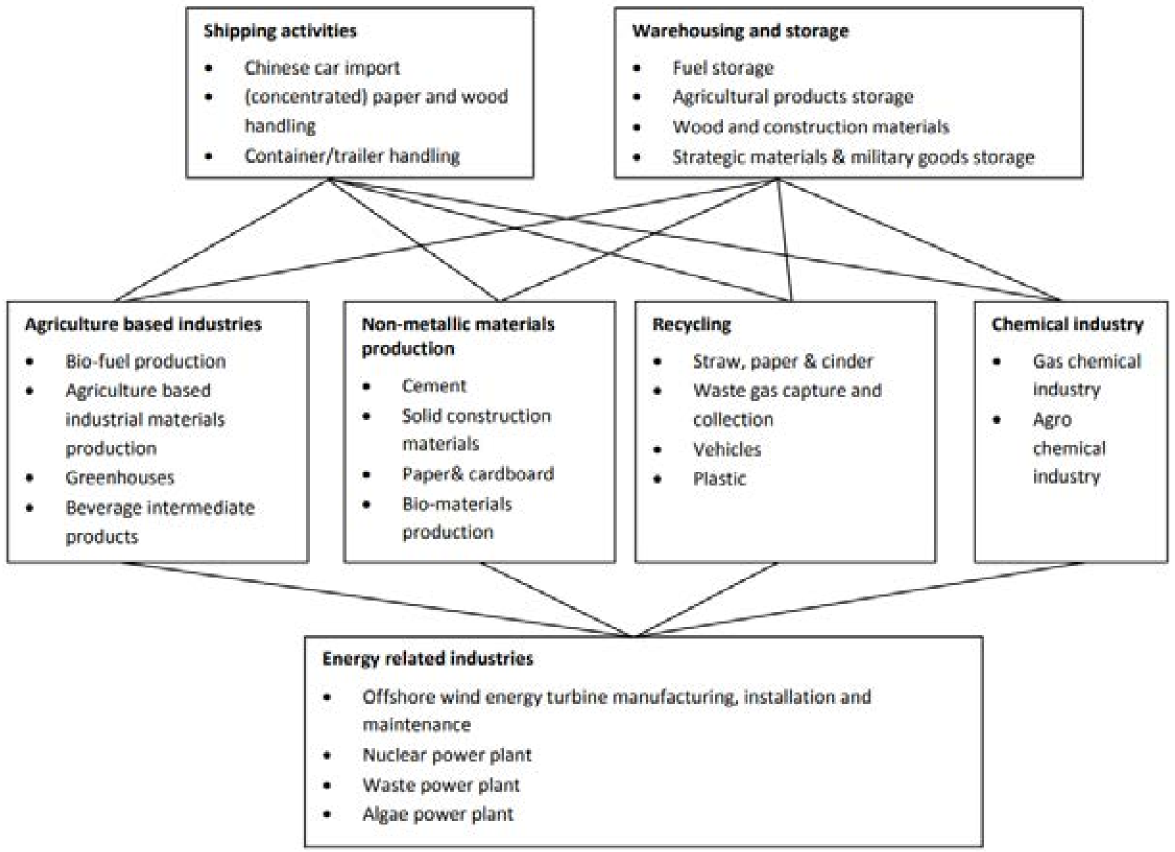

Figure 5.2: Development plan of Eemshaven - Programs for senario 2 (Chen, 2011)
Source: http://resolver.tudelft.nl/uuid:623bdcbc-d448-47da-8cf8-50725e600b1e

OBJECTIVE

The graduation project aims to investigate the consequence of integrating two factors. The first one is the appropriate technique for the end-of-life wind turbine blades (EoL WTB), which will be resulted from the thematic research about various circular strategies for this material, in terms of environmental and economic effects. A number of practices related to this material mentioned above will be used as reference projects. The other factor is the outcome of site analysis, which is an applicable combination between the economic development and ideas of local people in Eemshaven. Along with that, seismic construction will be an additional technical requirement for the project.

THEMATIC RESEARCH

The research paper seeks to determine the most effective circular approach for the EoL WTB based on the several studies and references projects mentioned above. The selected approach will then be used as the primary technique to transform WTB into architectural elements.

Along with the chosen approach for designing with WTB, the design also aims to follow other requirements as below:
- Designing based on the unique properties of the WTB.
- Design for disassembly principles, or the theory of Open Buildings.
- Being efficiently constructed and deconstructed without producing waste.

SITE INVESTIGATION

As mentioned in the chapter Eemshaven in PROBLEM STATEMENT, the selected location is in Eemshaven, which is strongly related to the WTB. That city has one of the largest wind farms in the Netherlands, where approximately 150 wind turbine blades will be decommissioned in 2050 (thewindpower.net). Located in there are a number of industrial facilities that can manufacture wind blades and transport them from and to the construction site.

Besides the resources of the material, the context of Eemshaven also brings to the project numerous requirements, such as proposed programs must be based on the development plan of the city, masterplan should include smart combinations of various ideas from locals, developers, and the government. The design of buildings needs to follow the principles of the seismic structure to handle the Groningen earthquake.

RELEVANCE

TOWARDS SUSTAINABILITY

The chosen topic will contribute significantly to the long-term goal of the Dutch government, which is fully clean energy by 2050 (Jani et al., 2022). Not only supporting wind energy as the most cost-effective way to achieve that goal (Scheepens, 2021), the project will attempt to bring EoL WTB back to the market.

Since the waste does not end up in landfills or incinerators, there is also a beneficial environmental benefit from recycling waste or recovering objects, components, or elements. Extending the duration of waste streams has the added benefit of preventing the depletion of natural resources.

CONFLICTS BETWEEN STAKEHOLDERS

The project will look at how to collaborate with many stakeholders, including residents and developers, in order to determine their own benefits in the same place. The key goal of the development plan will be combining economic growth with proposals from the local community for sustainability, high quality of life, and natural enjoyment.

A NEW CHAPTER OF BUILDING TECHNIQUE

Numerous studies have been conducted to examine wind turbine blades as a potential new construction material. The more projects that have been made, the larger amount of EoL WTB will be possibly solved. This will eventually result in a collection of unique technical details about WTB in architecture. Similarly to Neufert, global data as a standard manual, or a toolbox for designing with those blades will be made in the further future.

QUESTIONS

OVERALL DESIGN QUESTION

How circular strategies for end-of-life wind turbine blades can be integrated efficiently with the development plan in the context of Eemshaven?

Context: The selected site will be in Eemshaven, Groningen, where three main factors are located, namely the resource of materials (wind farms), the factory (wind power-related facilities that can recycle WTB), and the construction area (following the future development plan). Those three selected aspects are close to each other, in order to minimize transportation costs and other environmental effects.

Thematic focus points: The research will investigate multiple circular strategies for EoL WTB. The purpose of it is to find the most efficient method or a combination of various methods to incorporate EoL WTB in architecture design.

Program: As mentioned in the chapter Programs & development plan above, the project will be based on the plan of Eemshaven. The timeline of Scenario 2 of that plan will be similar to the decommissioned year of WTB in the location. Therefore, the project will focus on programs in that Scenario (Figure 5.2), namely greenhouses, agricultural products storage, wind power-related facilities, etc. Other additional programs such as cultural and hospitality-related will be investigated during the research.

THEMATIC RESEARCH QUESTION

How are various effects of different circular strategies for end-of-life wind turbine blades (EoL WTB), in terms of economy and enrironment, including the materials used in manufacturing, material waste at various stages, transportation expenses and the energy consumption?

Sub-questions:
1. How many EoL WTB circular strategies have been made available?
2. What are their techniques and how much energy did each method consume?
3. How much waste was produced by each strategy?
4. What parameters are used to assess such strategies? (such as the economic value, environmental impacts, etc.)

The potential result of the research will lead to the appropriate method to treat EoL WTB, which will be later on integrated into the design process, based on Eemshaven.

METHODOLOGIES

In the Architectural Engineering studio, as discussed with the research tutor, a theoretical framework for the research process is not required. So in order to obtain solutions to the previously mentioned research and design questions a variety of methods for the research have been proposed, including:

- Literature study (LS)
- Materials Flow Analysis (MFA)
- Geographic Information System (GIS)
- Interviews (In)
- Reference project analysis (RPA)
- Multiple evaluations (ME)
- Site investigating (SI)
- Research by design (RbD)

LITERATURE STUDY (LS)

LS will play as a key role in collecting data for entire the research, especially for sub-questions 1 and 4. Based on various articles and previous studies, data for question 1 which were about different strategies for EoL WTB, can be briefly mentioned as reusing, recycling, repurposing, re-inventing/refusing. A more detailed investigation of them will be made by Material Flow Analysis and Interviews. The data for question 4 are economic value, environmental impacts, transportation, etc. This method will also be used to support the design part, such as investigating the location as well as its development plans, and searching for regulations of buildings, etc.

MATERIAL FLOW ANALYSIS (MFA)

MFA will be the main method to elaborate questions 2 and 3, with different strategies for EoL WTB, such as energy consumption, environmental impacts, monetary value, etc. This is a method whereby a system-wide view is taken to track a material throughout its lifecycle (Allesch and Brunner, 2017). The mass balance rule is the underlying principle of an MFA; for example, every mass that comes into the system must also exit it or stay inside it as stocks. It delivers a complete and consistent set of information about all flows and stocks of a particular material within a system, and through balancing inputs and outputs, the flows of wastes and environmental loadings become visible, and their sources can be identified (Brunner and Rechberger, 2004). Therefore, this method offers an overview of the processes the material experiences, where it goes and where it stays, and additionally allows for analysis of the interaction between such processes and the environment (Allesch and Brunner, 2017). A scheme for an MFA can be seen in Figure 7.1.

Although MFA remains a strong tool for assisting in policy discussions due to its potential to effectively communicate general material trends (Graedel, 2019), limitations of this method are uncertainties in the data used or missing data (Allesch and Brunner, 2015). This study approaches this drawback by including additional methods such as interviewing, in the further detailed investigation of WTB.

INTERVIEWS (In)

The interviews have taken place with representatives from the different wind farms, and wind power companies in the Netherlands, in order to determine qualitative data related to the specific technique that they have used to recycle or repurpose EoL WTB. The interviews will be of semi-structured nature. That means a certain number of open-ended questions have been formulated in advance, and during the interview, there is room for new questions to arise from the ongoing dialogue (DiCicco-Bloom and Crabtree, 2006). Additional communications such as video calls and e-mail contact with experts from related fields will be conducted to get better data if MFA and other methods can not complete information.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

GIS is an effective way to handle spatial data (Huisman and de By, 2009). In this research, GIS mapping will be an optional method to visualize and analyze locations of wind farms. In order to determine the relationship between them and the factories and the location of the project, GIS will be used for network analysis. Network analysis is commonly applied to questions of logistics and lends itself well to incorporating characteristics such as transport distance and costs (Huisman and de By, 2009).

OTHER METHODS

After those 3 methods, Multiple evaluations (ME) will summarise the result of the research. Parallel with that, Site investigating (SI) will play a key role to investigate Eemshaven. Outcomes from those research processes will be imported into the design process with two other methods: Research by design (RbD) and Reference project analysis (RPA). Illustrations related to them can be seen in the Appendix (Figures 14.1, 14.2, and 14.3).

A broad overview of how these methods are integrated with the research and design process will be demonstrated in the next chapter.

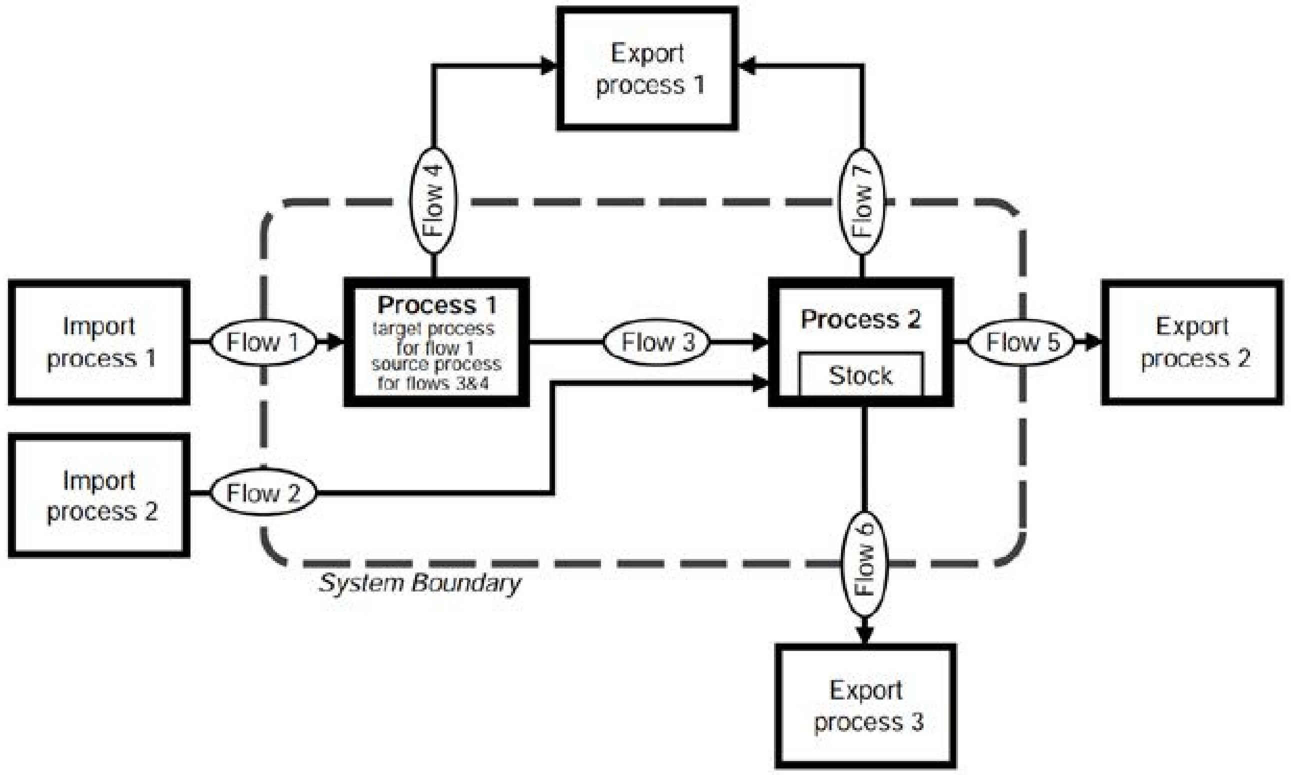

Figure 7.1: Exemplary MFA system illustrating selected terms (Brunner and Rechberger, 2004)
Source: https://www.scribd.com/document/331346816/Material-Flow-Analysis-Practical-Handbook-Brunner-Rechberger-1

RESEARCH & DESIGN STRUCTURE

A. THEMATIC RESEARCH STRUCTURE

A1. CONTEXT AND BACKGROUND

A1.1. Broad context of sustainable energy and the circular economy
A1.2. Situation of energy in Europe and the Netherlands
- Increasing demands as an increasing population
- Strategies on energy development to avoid the fuel energy, esspecially after the recent war of Russia
- Developing and making the most of renewable energy such as wind turbine is inevitable

LS

A2. END-OF-LIFE WIND TURBINE BLADES (WTB)

A2.1. Life cycle of WTB
- After 20-25 years, WTB have been replaced by the new one
- New types of blades bring more energy as well more monetary value

2.2. WTB is difficult to decompose
- Design of the blades in terms of material composition, size and mass
- Qualities of WTB (structure, soundproofing, light weight, etc.)

2.3. Consequences of WTB
- Being end up with landfills, as examples from America

LS

A3. CIRCULAR STRATEGIES END-OF-LIFE FOR WTB

A3.1. Circular strategies - broad view
- From R0-Refuse to R9-Recover

A3.2. Recent circular strategies for WTB
- Reuse - Recycle - Repurpose - Refuse/re-invent

LS

A4. CRITERIA TO EVALUATE CIRCULAR STRATEGIES

A4.1. Energy consumption and Environmental impacts
A4.2. Economic potential and monetary value
A4.3. Transportation of Onshore and Offshore WTB
A4.4. Other criteria

LS

A5. INVESTIGATING MULTIPLE CIRCULAR STRATEGIES FOR END-OF-LIFE WTB

A5.1. Reuse
- Opportunities to installation in less mature market (such as developing countries)

A5.2. Repurpose
- Using maximum blade's existing form for a new purpose or application

A5.3. Recycle
- Thermo-chemical methods
- Mechanical methods

A5.4. Re-invent (refuse using old types of WTB)
- New type of WTB that can be decomposed, example from CETEC

LS, MFA, GIS, In

A6. EVALUATION AND CONCLUSION

A6.1. Evaluating and interpretation
A matrix that shows impacts of different strategies (A5) based on different criteria (A4)

A6.2. Potential adaptation of the most circular strategy in the context of Eemshaven

The selected strategy or a combination of strategies should have the minimum negative impacts

A6.3. Suggestion for further research

LS, ME

B. SITE ANALYSIS

B1. LOCATION OF WTB

B1.1. Eemshaven - Area of industries and agriculture
B1.2. A collection of wind farms
- Data of Wind farms
- Data of Wind turbine blades

LS, SI

B2. DEVELOPEMENT PLANS

B2.1. Historical development of Eemshaven
B2.2. Recent plans
- Short term (future 5-10 years, small changes)
- Long term (future 20-30 years, large expansion)

LS, SI

B3. CURRENT SITUATION

B3.1. Regular earthquake
- Gas extraction leads to earthquake
- Earthquake resistant
  - Politic solutions
  - Theorical structure
  - Buildings as references

B3.2. Conflicts between villagers, developers and the government
- Visions of the developers
- Visions from villagers
- Strategies of the government

LS, SI, In

B4. BUILDING REGULATION

B4.1. Building's regulation in Eemshaven
B4.2. Adapting with the new material - WTB

LS, SI

C. PROGRAM ADAPTATION

C1. PROGRAM

C1.1. Intergrating data, following:
Multiple circular strategies for WTB
Different development plans (short and long terms)
Different stakeholders (villagers, developers, the government)

C1.2. Short term programs
C1.3. Long term programs

LS, SI, In

C2. MASTERPLAN

C2.1. Masterplan for short term based on
- Data of the location - B1
- Programs - C1.2

C2.2. Masterplan for long term based on
- Data of the location - B1
- Programs - C2.2

RbD, MFA, GIS

D. DESIGN INTEGRATION

D1. SKETCH DESIGN WITH WTB

D1.1. Reference projects with WTB
D1.2. Toolbox - potential adaptations of WTB in architecture, based on
- References - D1.1
- Data of WTB - B1
- Regulation - B4

RbD, RPA

D2. CONCEPT DESIGN WITH WTB

D2.1. Reference projects with WTB in the similar scale
D2.2. Design study based on:
- Selected master plan - C2
- Selected program (building)
- Selected WTB (size and shape)
- Toolbox - D1.2
- Selected circular strategies for WTB - A6

RbD

E. TECHNICAL INTEGRATION

E1. TECHNICAL INVESTIGATION WITH WTB

E1.1. Reference details with WTB or comparable materials
E1.2. Toolbox - potential details of WTB in architecture, based on
- References - E1.1
- Data of WTB - B1

RbD, RPA

E2. DETAILED DESIGN WITH WTB

Detailed design study based on:
- Concept design - D2.2
- Selected WTB (size and shape)
- Selected circular strategies for WTB - A6
- Toolbox - E1.2

RbD

PLANNING

Based on the research and design structure, the plan has been made as below. The research paper will be submitted before Christmas, following the discussion between the author and the research tutor.

A. THEMATIC RESEARCH STRUCTURE

A1. CONTEXT AND BACKGROUND

A1.1. Broad context of sustainable energy and the circular economy
A1.2. Situation of energy in Europe and the Netherlands
Increasing demands as an increasing population
Strategies on energy development to avoid the fuel energy, esspecially after the recent war of Russia
Developing and making the most of renewable energy such as wind turbine is inevitable

LS

A2. END-OF-LIFE WIND TURBINE BLADES (WTB)

A2.1. Life cycle of WTB
After 20-25 years, WTB have been replaced by the new one
New types of blades bring more energy as well more monetary value

2.2. WTB is difficult to decompose
Design of the blades in terms of material composition, size and mass
Qualities of WTB (structure, soundproofing, light weight, etc.)

2.3. Consequences of WTB
Being end up with landfills, as examples from America

LS

A3. CIRCULAR STRATEGIES END-OF-LIFE FOR WTB

A3.1. Circular strategies - broad view
From R0-Refuse to R9-Recover

A3.2. Recent circular strategies for WTB
Reuse - Recycle - Repurpose - Refuse/re-invent

LS

A4. CRITERIA TO EVALUATE CIRCULAR STRATEGIES

A4.1. Energy consumption and Environmental impacts
A4.2. Economic potential and monetary value
A4.3. Transportation of Onshore and Offshore WTB
A4.4. Other criteria

LS

A5. INVESTIGATING MULTIPLE CIRCULAR STRATEGIES FOR END-OF-LIFE WTB

A5.1. Reuse
Opportunities to installation in less mature market (such as developing countries)

A5.2. Repurpose
Using maximum blade's existing form for a new purpose or application

A5.3. Recycle
Thermo-chemical methods
Mechanical methods

A5.4. Re-invent (refuse using old types of WTB)
New type of WTB that can be decomposed, example from CETEC

LS, MFA, GIS, In

A6. EVALUATION AND CONCLUSION

A6.1. Evaluating and interpretation
A matrix that shows impacts of different strategies (A5) based on different criteria (A4)

A6.2. Potential adaptation of the most circular strategy in the context of Eemshaven

The selected strategy or a combination of strategies should have the minimum negative impacts

A6.3. Suggestion for further research

LS, ME

B. SITE ANALYSIS

B1. LOCATION OF WTB

B1.1. Eemshaven - Area of industries and agriculture
B1.2. A collection of wind farms
Data of Wind farms
Data of Wind turbine blades

LS, SI

B2. DEVELOPEMENT PLANS

B2.1. Historical development of Eemshaven
B2.2. Recent plans
Short term (future 5-10 years, small changes)
Long term (future 20-30 years, large expansion)

LS, SI

B3. CURRENT SITUATION

B3.1. Regular earthquake
Gas extraction leads to earthquake
Earthquake resistant
Politic solutions
Theorical structure
Buildings as references

B3.2. Conflicts between villagers, developers and the government
Visions of the developers
Visions from villagers
Strategies of the government

LS, SI, In

B4. BUILDING REGULATION

B4.1. Building's regulation in Eemshaven
B4.2. Adapting with the new material - WTB

LS, SI

C. PROGRAM ADAPTATION

C1. PROGRAM

C1.1. Intergrating data, following:
Multiple circular strategies for WTB
Different development plans (short and long terms)
Different stakeholders (villagers, developers, the government)

C1.2. Short term programs
C1.3. Long term programs

LS, SI, In

C2. MASTERPLAN

C2.1. Masterplan for short term based on
Data of the location - B1
Programs - C1.2
C2.2. Masterplan for long term based on
Data of the location - B1
Programs - C2.2

RbD, MFA, GIS

D. DESIGN INTEGRATION

D1. SKETCH DESIGN WITH WTB

D1.1. Reference projects with WTB
D1.2. Toolbox - potential adaptations of WTB in architecture, based on
References - D1.1
Data of WTB - B1
Regulation - B4

RbD, RPA

D2. CONCEPT DESIGN WITH WTB

D2.1. Reference projects with WTB in the similar scale
D2.2. Design study based on:
Selected master plan - C2
Selected program (building)
Selected WTB (size and shape)
Toolbox - D1.2
Selected circular strategies for WTB - A6

RbD

E. TECHNICAL INTEGRATION

E1. TECHNICAL INVESTIGATION WITH WTB

E1.1. Reference details with WTB or comparable materials
E1.2. Toolbox - potential details of WTB in architecture, based on
References - E1.1
Data of WTB - B1

RbD, RPA

E2. DETAILED DESIGN WITH WTB

Detailed design study based on:
Concept design - D2.2
Selected WTB (size and shape)
Selected circular strategies for WTB - A6
Toolbox - E1.2

RbD

WEEK	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	2.1	2.2	2.3	2.4	2.5	2.6	XMAS	XMAS	2.7	2.8	2.9	2.10	SPRING	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10
A	A1			A2			A3	A4	PREPARATION	P1	A5			A6	PREPARATION	P2 (SUBMIT PAPERS)						P2 (PRESENTA-TION)									P3							P4					P5
B		B1			B3		B2				B2		B3		B4				B4	B2	PREPARATION																						
C						C1					C1								C2					C2																			
D						D1					D1								D2					D2								D2											
E																			E1					E1			E2					E2							UPDATING PROJECT & MAKING MODELS			PREPARATION	

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APPENDIX

Figure 10.1: Installation, Dutch Design Week (Blade-Made, 2022)
Source: own photo

Figure 10.2: Blade Barrier (Blade-Made, 2022)
Source: http://resolver.tudelft.nl/uuid:7e0a1f8b-895c-4912-892f-3160284a68cb

Figure 10.3: BladeBridge, Ireland (ReWind, 2022)
Source: https://www.re-wind.info/

Figure 10.4: Bike shelter, Denmark (Siemens Gamesa, 2021)
Source: https://www.designboom.com/design/denmark-repurposing-wind-turbine-blades-bike-garages-09-27-2021/

Figure 10.1: Installation, Dutch Design Week (Blade-Made, 2022)
Source: Denis Guzzo

Figure 10.7: Wikado playground, Roterdam(Superuse, 2009)
Source: https://www.superuse-studios.com/nl/projectplus/blade-made-speeltuin-wikado/

Figure 10.6: Urban furniture, Terneuzen (Superuse, 2018)
Source: https://projects.superuse-studios.com/projects/rewind-oost-pier-terneuzen/

Figure 10.2: Wikado playground, Terneuzen (Superuse, 2016)
Source: https://projects.superuse-studios.com/projects/speeltuin-wikado-terneuzen/

Figure 11.1: Housing in Eindhoven (Crooijmans, 2022)
Source: https://research.tue.nl/nl/studentTheses/the-blade-of-eindhoven

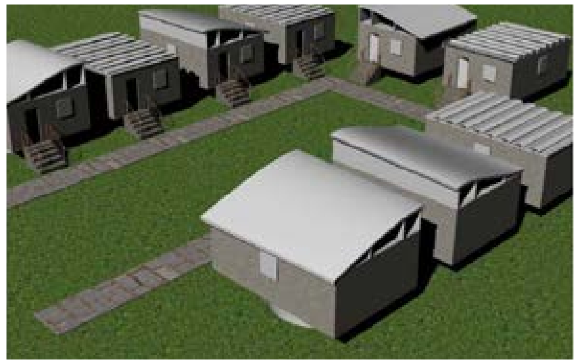


Figure 11.2: BladeShelters (ReWind, 2021)
Source: https://www.re-wind.info/

Figure 11.3: Feed Bunks (ReWind, 2021)
Source: https://www.re-wind.info/

Figure 12.1: Skis made of EoL WTB, Vattenfall (Gjenkraft, 2022)
Source: https://group.vattenfall.com/press-and-media/newsroom/2022/old-dutch-wind-turbine-blades-becomes-new-skis

Figure 12.2: Outdoor furniture, Poland (AIRchitecture, 2019)
Source: https://www.thefirstnews.com/article/the-green-team-turning-disused-wind-turbines-into-stylish-street-and-garden-furniture-10543

Figure 12.3: Indoor furniture, Milan (Tarantik & Egger, 2019)
Source: https://sdtkarlsruhe.de/a-2nd-life-for-rotor-blades-sdt-team-presents-prototype-at-milano-design-week-2019

Figure 13.1: 747 Wing house, Malibu (David Hertz, 2011)
Source: https://www.archdaily.com/165172/747-wing-house-david-hertz-architects

APPENDIX

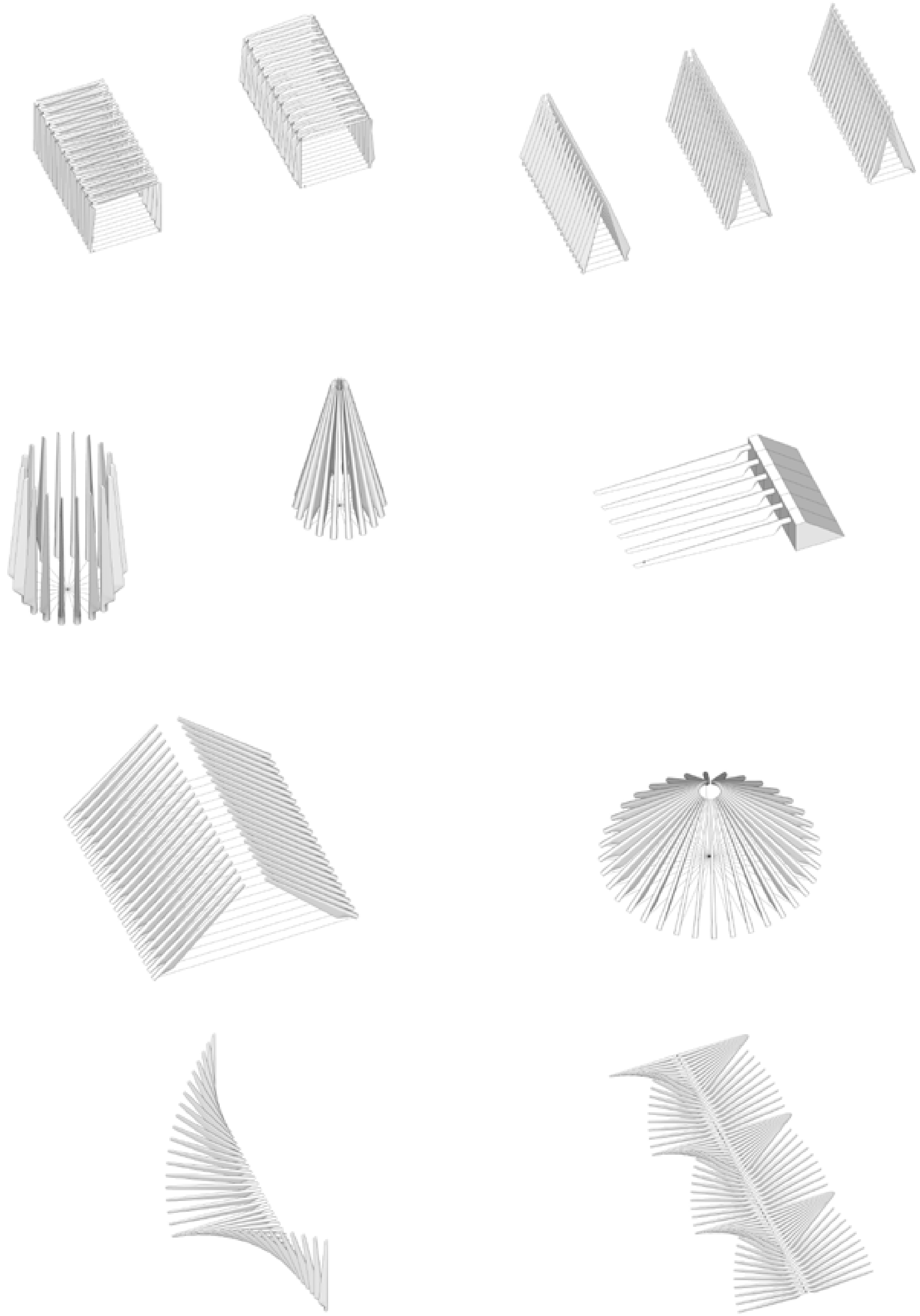


Figure 14.1: morphologic compositions of WTB
Source: own photo

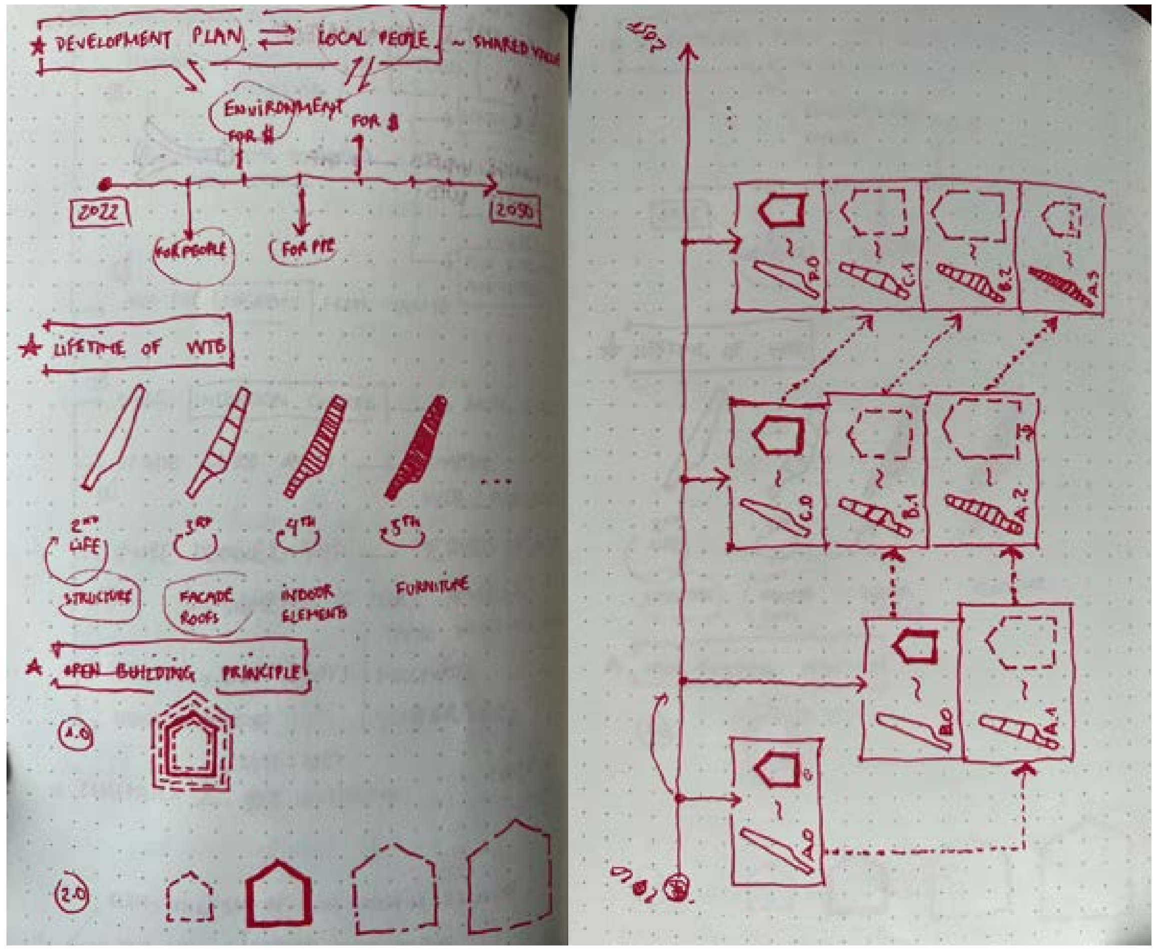
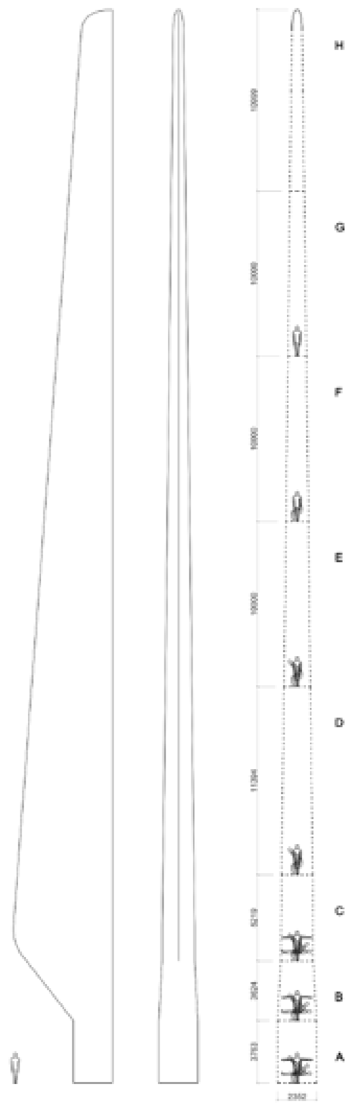


Figure 14.2: design strategy for expanding the lifetime of WTB
Source: own photo



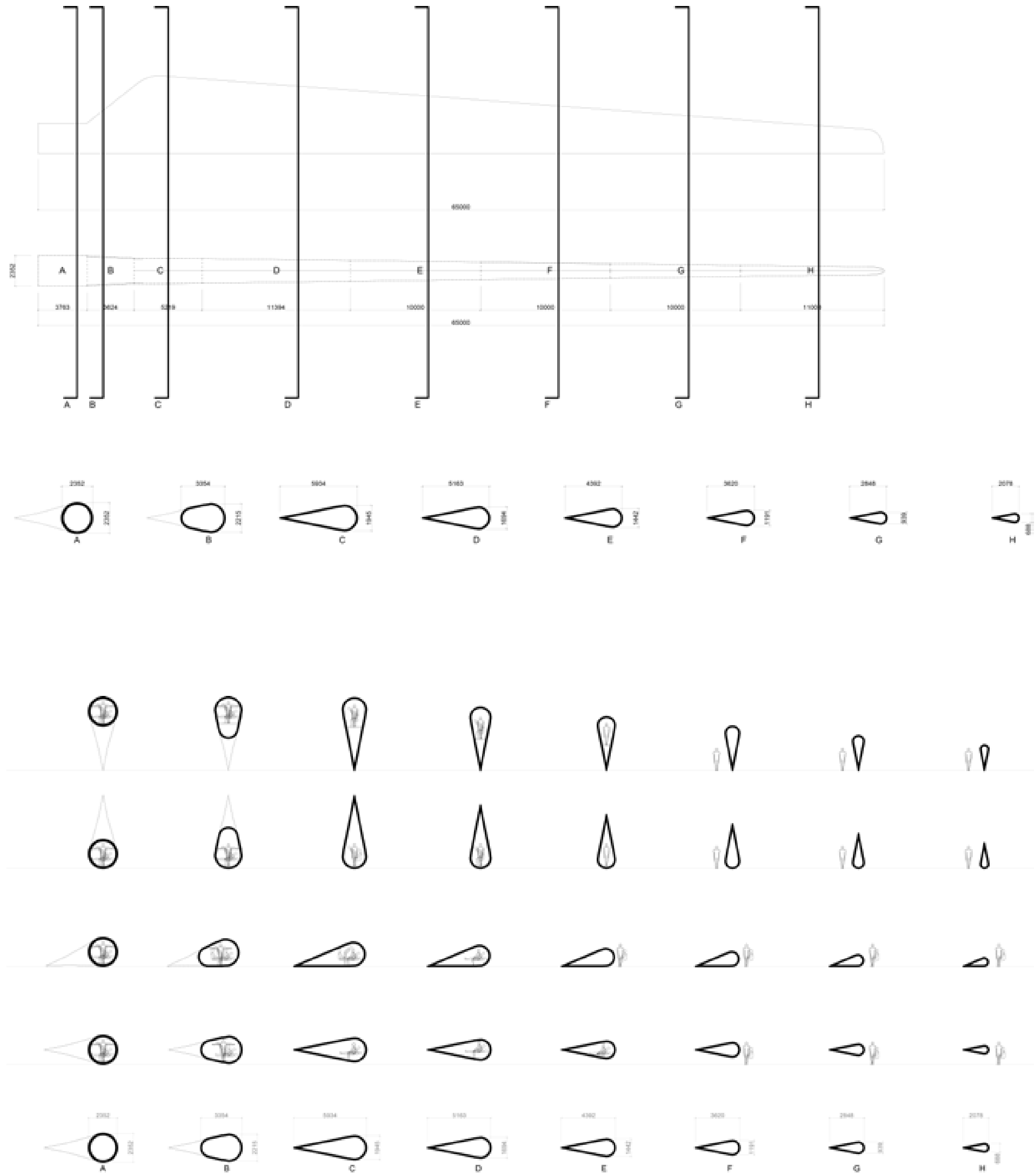


Figure 14.3: multiple studies of the relation between human scale and WTB
Source: own photo