GRADUATION PLAN I AE STUDIO

Personal Information

Name	Ruben Tjebbe Steinfort
Student number	5675138

Studio	Architectural Engineering
Name of studio	Stephan Verkuijlen
Design tutor	Mo Smit
Research tutor	

Argumentations of choice of the studio:

The combination of engineering and architecture has always captivated me, and I'm eager to be at the forefront of architectural innovation using cutting-edge methods and materials that may shape the architectural language of tomorrow.

Title

A new vision on lightweight fiber-based building systems using coreless-filament winding

Graduation Project

Keywords

Bespoke fibrous tectonics, Biobased, Computational design, Coreless-filament winding, Dematerialization, Demountability, Flax fibers, Fiber-based building systems, Modularity.

Location

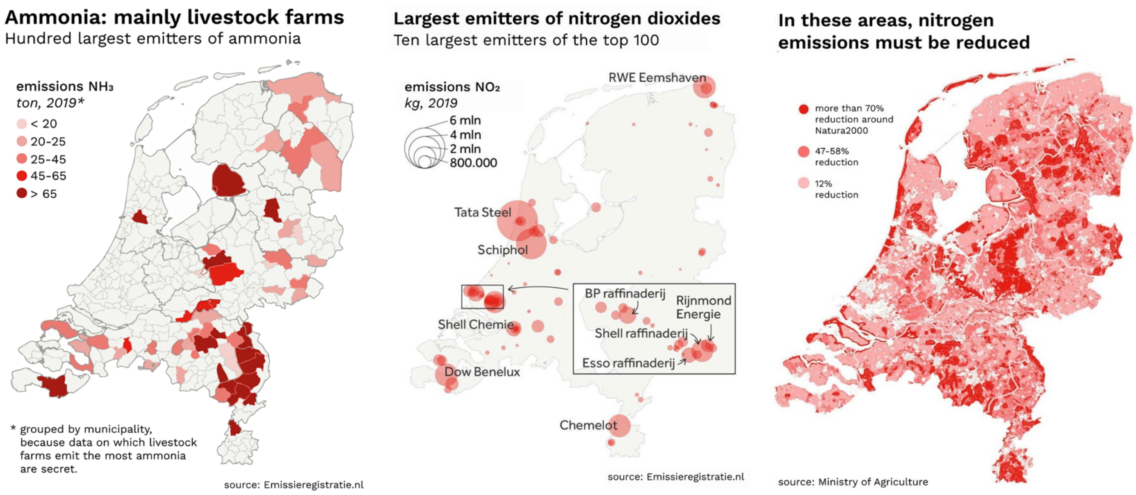
Northeast Groningen, The Netherlands

Problem Statement

One of society's most pressing environmental issues is the rising demand for new resource efficient building materials and methods (ECESP, 2021). However, rather than reducing the materials utilized, innovations in the building industry focused on lowering the cost through standardization, resulting in significant waste, pollution, and gas emissions. This trend resulted in a slight increase in efficiency, but in comparison with the manufacturing industry the building industry is falling behind (Mckinsey, 2017) [See appendix 1]. A need for an increase in resource efficiency of structures and the productivity of our building processes is key for the future of the industry. According to INJArchitects lightweight constructions are from an ecological, social and cultural standpoint beneficial to our society. Due to less waste material, feasibility to disassemble and recycle or compost and the production and assembly results in increased employment (INJ, 2023). Although steel has been an efficient material to use in lightweight structures the introduction of steel in the industrial revolution has started the exhaustion of our planet and therefore new materials need to be researched thoroughly to reverse this trend. Lightweight structures can also be constituted from fibrous materials, such as: carbon-, glass- and remarkably flax fibers. These materials have higher tensile strengths, are lighter and emit less CO_2 than steel. Lastly, research has shown that flax fibers can be harvested on soils in North-Western Europe

(Vleesschouwers, 2020). In conclusion, based on the considerations presented, flax can be considered the most potent material for constructing lightweight structures. Furthermore, the manufacturing industry has been capable of increasing their production efficiency due to the large quantities it can produce with minimal variations. The building industry mostly relies on the variations in end products and therefore cannot utilize the same techniques. As Jan Knippers, Professor at the Institute of Building Structures and Structural Design on the University of Stuttgart, states: “we as architects and engineers have to develop our own fabrication processes adapted for the needs of architectural and building construction” (Pérez, Guo, & Knippers, 2022). A technique that uses the material characteristics of fibers, such as Flax, is coreless-filament winding (CFW). Although the introduction of coreless-filament winding is optimistic, a research gap is present. The aim of this study is to close the knowledge gap on how to design and fabricate lightweight, material-efficient (dematerialized) modular, aesthetically valued (bespoke fiber tectonics) load-bearing structures for large spans that can be integrated with building envelopes to form fiber-based building systems using the coreless-filament winding technique and regionally harvested flax.

Contextually The Netherlands, like several European countries, confronts a significant nitrogen crisis, illustrated in figure 3, resulting from the continuous expansion of the livestock, construction, and industrial sectors (Ministerie van Binnenlandse Zaken en Koninkrijkrelaties, 2019). This crisis has led to a slowdown in construction projects near Natura 2000 regions and necessitates about 3,000 livestock farms to adapt or cease their operations (Rijksoverheid, 2023). The lack of innovation in these sectors exacerbates the problem.



a *b* *c*

Figure 3: Ammonia and Nitrogen emission in The Netherlands (translated)
Graphs retrieved from: Het stikstofprobleem is echt Nederlands, uitgelegd in acht grafieken [Graph]. NOS. Accessed on January 25, 2024, www.nos.nl

Focusing on the Northern Netherlands, demographic challenges have emerged, including a declining population and an aging demographic due to urban migration, causing socio-economic issues, illustrated in figure 4 and 5 (CBS, 2022). The agriculture industry also faces succession problems (Bakker, 2021). A potential solution lies in modernizing these industries, promoting youth involvement, and exploring synergies between farming and construction. Such innovations can address the nitrogen crisis and enhance economic prospects in the region while fostering environmental sustainability.

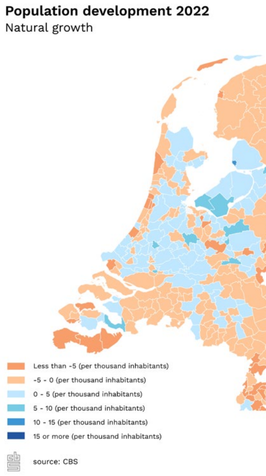


Figure 4: Northern Netherlands faces a demographic decline in natural growth (CBS, 2022)
Graph retrieved from: Population Development 2022 [Graph]. Harveyotten. Accessed on January 25, 2024, www.Harveyotten.nl

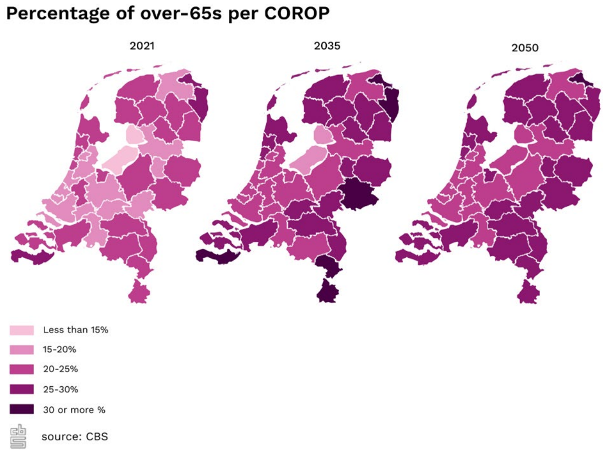


Figure 5: Additionally the Northern region has an aging problem (CBS, 2022)
Graph retrieved from: Percentage of over-65s per COROP [Graph]. Kennisvanstadenregio. Accessed on January 25, 2024, www.kennisvanstadenregio.nl

This to create a circular economy whereby farmers can harvest crops that can be used as biobased building materials in the building sector. Such a biobased material can be for example: Flax, a fiber that can be grown on clayish soils in the Northern part of the Netherlands.

Historically seen, the province of Groningen, in the Northern part of The Netherlands, had a flourishing flax industry in the 1950's (Brouwers, 1957). The province of Groningen wants to bring back this industry back by reintroducing flax fields (Hofslot, 2023).

What if the building- and farming industry join forces to grow biobased materials in regional landscapes that can be used for the building industry. By creating a pilot project that showcases the possibilities with the use of flax fibers the Northern region of The Netherlands can benefit greatly.

A region plagued by the disastrous earthquake problems that were the result of the long lasting tunnel vision of the Dutch government that saw Groningen only as a profitable region for their gas fields. Now is the time for the region to showcase its potential as a key factor in combating the nitrogen crisis in the agricultural sector and as a mayor player to fulfill the need for building materials.

By doing so we can recreate a synergy not only between farmers, builders and the inhabitants, but with nature itself.

Thematic Research Questions
For the thematic research the formulated research question is stated below:

"How to create lightweight fiber-based building systems for large open spaces from (regionally harvested) flax fibers using coreless-filament winding, whereby bespoke fibrous tectonics, dematerialization and modularity are considered as guiding themes?"

The thematic research is segmented into three distinctive interrelated themes i.e. dematerialization & decarbonization, production of fibrous tectonics and modularity & demountability. The main research question is subdivided into five sub-questions.

<u>Dematerialization & Decarbonization</u>
1. What are the characteristics of (flax) fibers that need consideration to use the material with the coreless-filament winding technique to achieve dematerialized fibrous structures?

2. How are flax fibers harvested, processed, and finalized to be used for coreless-filament winding and how can the biodegradability of the end product be ensured?

<u>Production of fibrous tectonics</u>
3. How can the fabrication technique of coreless-filament winding be optimally used with flax and other types of fiber-based materials resulting in dematerialized modular structures characterized by fibrous tectonics?

<u>Modularity & Demountability</u>
4. How can these structural and non-structural fibrous elements be combined in a modular and demountable way, while being thermally insulated, weatherproof and structurally optimized, to form fiber-based building systems?

5. How can computational design aid in creating fibrous structures that utilize dematerialization, are structurally optimized for the shapes needed for the program and enable form freedom?

Methodologies

Sub research question	*Target Data*	*Collection method*	*Analysis method*	*Expected result*
1. What are the characteristics of (flax) fibers that need consideration to use the material with the coreless-filament winding technique to achieve dematerialized fibrous structures?	Material characteristics of primarily flax fibers and other types of fibrous filament winding (FW) materials	Literature study and Interview	Comparative analysis of performances	List of filament winding materials assessed on the basis of the formulated performance indicators. Which formulates design preconditions for using flax fibers
2. How are flax fibers harvested, processed, and finalized to be used for coreless-filament winding and how can the biodegradability of the end product be ensured?	Information on the techniques of harvesting and processing flax and its Life Cycle Analysis	Literature study and Interview	Literature review	Diagram illustrating the full life cycle of flax fibers from crop to filament to end-of-life
3. How can the fabrication technique of coreless-filament winding be optimally used with flax and other types of fiber-based materials resulting in dematerialized modular structures characterized by fibrous tectonics?	Information on the coreless-filament winding technique and which are the key procedures	Literature study, Case study, Interview	Literature review and Case study analysis	Insight in how the fabrication technique works, what the key procedures are to take into account and why it was invented
4. How can these structural and non-structural fibrous elements be combined in a modular and demountable way, while being thermally insulated, weatherproof and structurally optimized, to form fiber-based building systems?	Data from prototyping and Research-by-Design on how to create fiber-based building systems on thermal, weatherproofing and structural aspects	Case study, Interview, Research-by-Design and Prototyping with the knowledge gathered from SQ1 to SQ3.	Case study analysis, Interview, Comparative analysis, Prototyping experiments	Various potent design options for fiber-based building systems
5. How can computational design aid in creating fibrous structures that utilize dematerialization, are structurally optimized for the shapes needed for the program and enable form freedom?	Key aspects of using computational design and AI in the digital design and fabrication process of coreless-filament winding	Literature study, Interview	Literature review	Knowledge on how computational design is used in coreless-filament winding and how it effects the fibrous end products

Design assignment
In this project the outcomes of the thematic research on the building material Flax, with a combination of other fibrous materials, such as carbon fibers and glass fibers, that is conducted on a micro level in which structures, characteristics, strengths and weaknesses of the material are analyzed, will be used. Additionally, by doing so a comprehensive list of design preconditions for these kind of fibrous structures can be formulated and used in the design process.

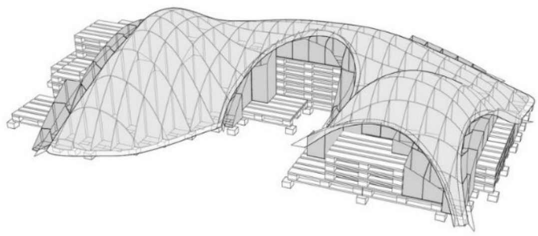


Figure 6: Image retrieved from: Design research on new tile vaulting [Image]. BRG. Accessed on January 25, 2024, www.block.arch.ethz.ch

The design project focuses on the farm of the future which is constructed using coreless-filament winding (CFW) and is constituted out of fibrous structures. The aim of the project is to design a farm which is incorporated into the Groninger landscape and uses regional fibrous sources, such as Flax. Therefore, potent fibrous structures that are constituted from the thematic research are explored and integrated into the design. The goal, firstly, is to design various potent layouts which are the most suitable for the required infrastructure for flax farm activities and to promote a smooth workflow and efficiency between the facilities. Secondly, in the architectural design a space for community engagement, education and events is desired to showcase the full potential of flax as building material and to educate and inspire people. Lastly, the ambition is to explore the transformative impact of this new architectural language on the connection between humans and their living environment.

Design Hypothesis
For the design assignment a design hypothesis is formulated which states:

The flax farm of the future, that is constituted from fibrous structures, and which is constructed using coreless-filament winding, will have a positive impact on the layout, the efficiency of the required facilities and translates into a new architectural language that has a transformative impact on the relationship between humans and their environment and ultimately showcases the full potential of the use of flax in Architecture.

Additionally, to verify this hypothesis five sub-questions have been formulated:

1. Which materials and construction techniques, both historically and contemporary, have been used to accommodate different farm typologies in The Netherlands and abroad?

2. What are the geographical and climatic characteristics of the site, in the Groninger landscape, that needs to be considered, and how do they influence the design?

3. What infrastructure is required for flax farm activities, including storage, processing, production and packaging and which layout is the most suitable to use in the design to promote a smooth workflow and efficiency between the facilities?

4. How can the architectural design of the farm include spaces for community engagement, education and events to showcase the potential and the production cycle of Flax?

5. How do these materials and techniques alter the way we are connected to our living environment and result in a new architectural language?

This hypothesis suggests a study of the materials and construction methods employed in different farm typologies, in The Netherlands and around the world, both historically and contemporary. It also acknowledges the importance of understanding the geographical and climatic characteristics of the Groninger landscape in shaping the design. Furthermore, the hypothesis calls for a review of the infrastructure required for flax farming activities and the potential for creating educational facilities or visitor centers to showcase flax harvesting, production and the construction of flax fibrous structures using CFW. Ultimately, the hypothesis highlights the transformative impact of chosen materials and techniques on the relationship between humans and their environment, aiming to identify a new architectural language specific to flax farm typologies.

Methodologies

Sub research question	*Target Data*	*Collection method*	*Analysis method*	*Expected result*
1. Which materials and construction techniques, both historically and contemporary, have been used to accommodate different farm and factory typologies in The Netherlands and abroad?	Structural typologies of farms and factories, Used materials	Case study	Case study analysis	Investigation of the various types of materials and structures that have been used for various farm and factory typologies
2. What are the geographical and climatic characteristics of the site, in the Groninger landscape, that needs to be considered, and how do they influence the design?	Site characteristics which need to be taken into account and information on how to implement this in the design	Field Research, Literature study, Location analysis, Interview(s)	Literature review, Context analysis, Interview(s)	Map of the geographical and climatic characteristics of the site which will be used in the design
3. What infrastructure is required for flax farm activities, including storage, processing, production and packaging and which layout is the most suitable to use in the design to promote a smooth workflow and efficiency between the facilities?	Plan layouts and information on which infrastructure is needed for harvesting, processing and coreless-filament winding	Literature study Field Research Interview(s) Research-by-Design	Literature review Interview(s) Analysis based on performance indicators	Comprehensive overview of required infrastructure and an explorative overview of various potential plan layouts for the design
4. How can the architectural design of the farm include spaces for community engagement, education and events to showcase the potential and the production cycle of Flax?	Information on community engagement in the design	Case study, Literature study, Research-by-Design	Case study analysis Literature review	An investigation and exploration of parameters on how to implement community engagement in the design
5. How do these materials and techniques alter the way we are connected to our living environment and result in a new architectural language? for the program and enable form freedom?	Empirical information on the influences of architecture	Literature study	Literature review	Comprehensive overview of impacts of fibrous architecture and insights on which characteristics of architecture effects humans empirically

Literature

1. Bakker, K. (2021, Januari 14). *'Gebrek aan jonge boeren is een groot probleem'*. Retrieved from Boerenbusiness: https://www.boerenbusiness.nl/agribusiness/artikel/10890648/gebrek-aan-jonge-boeren-is-een-groot-probleem
2. Brouwers, A. (1957). *DE VLASSERIJ IN HET NEDERLANDS VAN DE EERSTE HELFT DER TWINTIGSTE EEUW.*
3. Brutch, N., Soret-Morvan, O., Porokhovinova, E., Sharov, I., & Morvan, C. (2008). Characters of fibre quality in lines of flax genetic collection. In *Journal of Natural Fibers, Volume 5, Issue 2* (Vol. 5, pp. 95-126). The Haworth Press.
4. CBS. (2022). *Regionale bevolkings- en huishoudensprognose 2022-2050*. Retrieved from CBS: https://longreads.cbs.nl/regionale-prognose-2022/vergrijzing/
5. CBS. (2022). *Waar groeit of krimpt de bevolking?* Retrieved from CBS: https://www.cbs.nl/nl-nl/dossier/dossier-verstedelijking/waar-groeit-of-krimpt-de-bevolking-
6. CLM. (2020). *Bijdrage van vlas en hennep aan milieu- en klimaatdoelstellingen van het toekomstig EU-landbouwbeleid.* Culemborg: CLM.
7. Duque Estrada, R., Kannenberg, F., Hans, ·., Wagner, J., Yablonina, M., & Menges, ·. (2020). Spatial winding: cooperative heterogeneous multi-robot system for fibrous structures. *Construction Robotics. 4*, pp. 205-215. Stuttgart: University of Stuttgart. Retrieved from https://doi.org/10.1007/s41693-020-00036-7
8. ECESP. (2021). *circular buildings and infrastructure.* Retrieved from https://circulareconomy.europa.eu/platform/sites/default/files/circular_buildings_and_infrastructure_brochure.pdf
9. Hofslot, G. v. (2023, September 13). *Bouwmateriaal, linoleum, papier. Vlas gedijt op Zernike Campus in Groningne. 'Dit gewas willen we heel graag terug hebben'*. Retrieved from Dagblad van het Noorden: https://dvhn.nl/economie/Vlas-gedijt-goed-op-de-Zernike-Campus-28636533.html
10. INJ. (2023, 3 27). *Lightweight Architecture: Innovate Materials and Construction Techniques*. Retrieved from INJ Architects: https://injarch.com/lightweight-architecture-innovative-materials-and-construction-techniques/
11. Kozłowski, R., & Mackiewicz-Talarczyk, M. (2020, 1). Introduction to natural textile fibres. In R. M. Kozłowski, & M. Mackiewicz-Talarczyk, *Handbook-of-Natural-Fibres, 2020* (Vol. 1, pp. 1-13). Poznan, Poland: Elsevier Inc.
12. Kozlowski, R., Batog, J., Konczewicz, W., Mackiewicz-Talarczyk, M., Muzyczek, M., Sedelnik, N., & Tanska, B. (2005). Latest state of the art in bast fibres bioprocessing. In R. Kozlowski, & M. Mackiewicz-Talarczyk, *Handbook-of-Natural-Fibres, 2020* (pp. 118-119). Poznan, Poland: Elsevier Inc.
13. Kozlowski, R., Batog, J., Konczewicz, W., Mackiewicz-Talarczyk, M., Muzyczek, M., Sedelnik, N., & Tanska, B. (2006a). Enzymes in bast fibrous plant processing. In R. Kozlowski, & M. Mackiewicz-Talarczyk, *Handbook-of-Natural-Fibres, 2020.* Poznan, Poland: Elsevier Inc.
14. Kozlowski, R., Batog, J., Konczewicz, W., Muzyczek, M., Sedelnik, N., & Tanska, B. (2006b). Survey and recent report on enzymatic processing of bast fibres. In R. Kozlowski, & M. Mackiewicz-Talarczyk, *Handbook-of-Natural-Fibres, 2020.* Poznan, Poland: Elsevier Inc.
15. Kozłowski, R., Mackiewicz-Talarczyk, M., Wielgusz, K., Praczyk, M., & Allam, A. (2020, 1). Bast fibres: Flax. In R. Kozłowski, & M. Mackiewicz-Talarczyk, *Handbook-of-Natural-Fibres, 2020* (Vol. 1, pp. 93-162). Poznan, Poland: Elsevier Inc.
16. Krap S, Straathof (DLG), Sleeking, Verlaat (DLG), & Janssen, V. (2017, 12). *PAS-gebiedsanalyse Waddenzee (001).*
17. McIntry, J., Denton, M., & Daniels, P. (2002). Textile terms and definitions. In R. Kozlowski, & M. Mackiewicz-Talarczyk, *Handbook of Natural Fibers, 2020* (pp. 97-106). Poznan, Poland: Elsevier Inc.
18. Mckinsey. (2017). *Reinventing construction: a route to higher productivity.* Retrieved from https://www.mckinsey.com/~/media/mckinsey/business%20functions/operations/our%20insights/reinventing%20construction%20through%20a%20productivity%20revolution/mgi-reinventing-construction-executive-summary.pdf

19. Menges, A., Kannenberg, F., & Zechmeister, C. (2022, Juli 25). *Computational co-design of fibrous architecture.* Springer. Retrieved from Springerlink: https://link.springer.com/article/10.1007/s44223-022-00004-x
20. Miller, T., & Elgård, P. (1998). *Design for Integration in Manufacturing.* Nordborg: Aalborg University. Retrieved from http://alvarestech.com/temp/PDP2011/CDAndrea/MODULARIDADE/MILLER%202005.pdf
21. Ministerie van Binnenlandse Zaken en Koninkrijkrelaties. (2019, Juli 2). *Woningbouwplannen, stikstof en Natura 2000-gebieden overzichtelijk gemaakt door factsheet*. Retrieved from Volkshuisvestingnederland: https://www.volkshuisvestingnederland.nl/actueel/nieuws/2019/07/02/woningbouwplannen-stikstof-en-natura-2000-gebieden-overzichtelijk-gemaakt-door-factsheet
22. Mohamed, A., & Hassabo, A. (2015). Chapter 10 Flame Retardant of Cellulosic Materials and Their Composites. In R. Kozlowski, & M. Mackiewicz-Talarczyk, *Handbook-of-Natural-Fibres* (pp. 247-314). Poznan, Poland: Springer Science and Business Media B.V.
23. Pérez, M., Früh, N., La Magna, R., & Knippers, J. (2022). *Integrative structural design of a timber-fibre hybrid building system fabricated through coreless filament winding: Maison Fibre.* Stuttgart: Elsevier Inc.
24. Pérez, M., Guo, Y., & Knippers, J. (2022). *Integrative material and structural design methods for natural fibres filament-wound composite structures: The LivMatS pavilion.* Stuttgart: Elsevier Inc.
25. Pérez, M., Rongen, B., Koslowski, V., & Knippers, J. (2021). *Structural design assisted by testing for modular coreless filament-wound composites: The BUGA Fibre Pavilion.* Stuttgart: Elsevier Inc.
26. Prado, M., Dörstelmann, M., Schwinn, T., & Menges, A. (2014). Core-Less Filament Winding. *Robots in Architecture Conference 2014.* University of Michigan.
27. Radkar, S. (2018). *Potential Applications of Flax Fibers.* Fargo, North Dakota: North Dakota State University of Agriculture and Applied Science.
28. Rijksoverheid. (2023). *Aanpak piekbelasting*. Retrieved from Aanpakstikstof: https://www.aanpakstikstof.nl/aanpak-piekbelasting
29. Schwartz, Chad; Ford, Edward R. (n.d.). *Introducing architectural tectonics : exploring the intersection of design and construction.* Retrieved from https://www.researchgate.net/publication/322253651_Introducing_Architectural_Tectonics_Exploring_the_Intersection_of_Design_and_Construction
30. Stamenkovi, V., Seager, S., Al-Alwan, A., & Mahmood, Y. (2020). The Connotation of Tectonics in Architectural Theory. *IOP Conf. Ser.: Mater. Sci. Eng. 745.*
31. Sultana, C. (1991). The influence of flax harvesting techniques on fibre quality. In R. Kozłowski, & M. Mackiewicz-Talarczyk, *Handbook of Natural Fibers, 2020.* Poznan, Poland: Elsevier Inc.
32. Vleesschouwers, B. (2020). *Dossier Vlasteelt.*
33. Walkowski, T., Ladek, A., & Piotrowska, A. (1998). Len oleisty. (Linseed). In R. Kozlowski, & M. Mackiewicz-Talarczyk, *Handbook-of-Natural-Fibres, 2020* (p. 107). Poznan, Poland: Elsevier Inc.

Reflection

What is the relation between your graduation project topic, the studio topic (if applicable), your master track (Architecture) and your master program (MSc AUBS)?

The relation between my graduation topic, The future fibrous flax farm with Architectural Engineering is the interrelationship between Architecture and Engineering itself and showcases architecture from a tectonic perspective. Therefore the relationship with the Master track of Architecture is relevant on the topics of Architectural Design and Theories. Lastly, the relationship with the master program MSc Architecture, Urbanism and Building sciences is closely related due to covering all the facets learned in my academic endeavors.

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

This graduation project is relevant due to the high level of innovation it can bring to the building industry. From a scientific point of view the in depth analysis of the fibrous material, flax, and its structural purposes to create lightweight structures and thereby reduce material waste, increase building efficiency and speed play a big role in the innovation it can bring. The translation of the techniques of coreless-filament winding into architectural practices which can be used in various building programs with large spans can benefit the field of architecture as well. The combination of the biobased material and the robotic technique result in more material and production efficiency whereby less material is wasted. This by connecting the necessary characteristics of a material that are needed for lightweight structures to its source, the soils, a true sustainable building cycle can be achieved. From a societal perspective the synergy between farmers (harvest), builders (production) and residents (living) can strengthen the cohesion in society. The design research can also have great effects on the image that has been portraited on the farm industry the last couple of decades. A new image can be resulted whereby a circular economy can be created, but also in the built environment itself with new farm typologies of the future which co-exist with nature and truly protect the natural environment. Additionally, a connection with the Groninger landscape can be made in the design and can therefore give farm architecture a new place in Groningen and The Netherlands. Lastly, from an economical and environmental perspective the combination of the biobased material and the robotic techniques can create prosperity, reduces the environmental impact of the industries and creates a consciousness in society that we truly can work with the environment instead of depleting it for our own purposes.

From an architectural point of view, a new architectural language may be discovered due to the bespoke fibrous tectonic structures created.