REED ROBOTICS
Discrete Digital Assembly of Biodegradable Reed Structures

Hayley Bouza
Building Technology Master
Student No. 4712366

Mentors
Dr. Serdar Aşut
Dr. Ing. Marcel Bilow

External Examiner
Dr. Sylvia Jansen

Reflection

I chose to graduate in the departments of Design Informatics and Building Product Innovation within the Building Technology Track. My interest is in applying digital design and fabrication strategies alongside sustainable materials to produce innovative architecture. This is closely related to the Building Technology Master as it involves engineering problems of material and computational research informed by architectural design drivers and focused on sustainability.

The design and construction of sustainable buildings is of key importance for the clean energy transition as building construction and operations continue to account for a substantial portion of energy related carbon dioxide emissions; 39% in 2017 (I.E.A., 2018). In the simplest terms, a building is a collection of materials, shaped and connected to enclose space. Therefore, it can be argued that material choices and production and assembly methods ultimately determine the sustainability of a building in terms of the amount of energy required for construction, the longevity and quality of the building, and the ecological impact. Common Reed (*Phragmites Australis*) is an abundantly available, sustainable construction material that can be found throughout the world. Reed has traditionally been used in Europe for thatch roofing, providing insulation and a weather-tight surface. Elsewhere, traditional techniques of weaving and bundling reeds have long been used to create entire buildings. This research develops a new alternative to these techniques with the aim of showcasing the ability of reed to perform as structure, insulation, and cladding all at once. Through an iterative process of designing from the micro to the macro scale and by experimenting with robotic assembly, the result is a reed-based system in the form of discrete components that can be configured to create a variety of structures. The project proposes a series of nature observation structures for the National Park Duinen van Texel. The structures are intended to last ten to twenty years and utilise completely biodegradable materials which can be disassembled whenever necessary. This semi-permanence allows for future flexibility and ensures preservation of the natural environment.

The project followed a research by design process that is rooted in material research and experimentation. Material-based design is an increasingly dominant design model that experiments with the synthesis of new digital techniques and material design and fabrication technologies in an experimental design model (Oxman, 2015). Materials have the greatest impact on a design, although through the creative treatment and assembly of materials, design possibilities can be expanded. Design should begin with experiential, functional and formal requirements. In material-based design, these requirements are still the primary design drivers, with the material shaped to meet the design goals.

The research method consisted of several components investigated in a non-linear process as learning from one aspect was reconsidered in relation to previous findings. These aspects included: (1) literature review, (2) material research and experimentation, (3) analysis of digital design and production methods, (4) physical prototyping and robotic testing (5) design case study.

At the beginning of the research, the first step was to determine which plant fiber to study. I researched many options and looked into plant fibers native to Europe, such as flax, hemp, and straw. Reed stood out as a material with several beneficial innate characteristics, particularly notable was the potential for the material to perform as structure, cladding, and insulation. I found that the material has been used in a few traditional ways, but little research into new methods of building with reed exist.

I began weaving reeds by hand and quickly realized how challenging it would be to do the same process with a robotic arm. Reeds are inconsistent, every stem has a different diameter across its length and some are straighter than others. Incorporating consistency ended up becoming the primary challenge in applying a digital fabrication process. As I was researching weaving, I came across the venus flower basket, a sea sponge with a woven structure. Zooming in on this structure it can be found that it is not made up of interlacing strands, but instead interlocking particles called spicules. Looking at other natural sponges I learned that spicules come in many shapes. This was a key moment as I realized I could take the same approach of forming a weave by aggregating interlocking reed bundles. Although the result is not a woven structure per se, it achieves the same effects. The reeds can form solid and open areas and there is an underlying pattern in their organization. In developing a shape for the reed bundles, I began with star shapes and the idea of a gravity based structure which would allow a random interlocking of the bundles, inspired by University of Stuttgart's 2018 ICD Aggregate Pavilion. The problem with this approach was the lack of control over the final form and structural strength. I moved on to develop a linear bundle with wood end connectors that serve to shape the reed in consistent square sections while providing a point of attachment. In testing all of these options I needed to work at both the scale of the connection detail and the resulting architecture as they are unavoidably intertwined, any change at one scale would influence the other.

At this stage I was also reading about digital processes in architecture and began to situate the project within the emerging ethos of digital architecture. The linear reed bundle becomes a discrete element that is capable of altering the outcome of the architectural form through modification of its length and position. These discrete methods use Cartesian geometries that create surface through the combination of orthogonal blocks, or voxels, capable of forming curvilinear space through adjusting their size and arrangement (Garcia, 2019).

The design of the wood end connectors went through many iterations in the form of sketches and physical models. I initially settled on a design which had six different joint types that interlocked vertically, using gravity to secure the connection. In digital space these joints worked very well and I constructed a 1:1 prototype from mdf and was still satisfied that they functioned well. However, as I needed to produce many of these joints at 1:2 scale for testing the robotic assembly, I could see that the design did not enable rapid prototyping. I simplified the design considerably by introducing an octagonal keyhole joint. This design allows for one consistent joint that can position the elements at 45, 90, or 135 degrees. By changing the lengths of the reeds and adjusting the placement of components, the resulting structure is modified. The elements are essentially all the same, but they enable mass customization by simply elongating or shortening the reeds.

The final stage of the project involves testing the robotic assembly. The design of the reed elements consumed most of my time, leaving the robotic tests until the end. Looking back, I should have been working with the robotic arm earlier in the process as this may have also helped to inform the design of the reed elements. The robotic assembly was simulated using the RoboDK programmer. A 1:2 prototype with six elements was built to test the assembly with the Universal Robots UR5 robotic arm.

During the process, my mentors helped to focus the research, as there are many ways in which it could expand. They provided regular feedback on the proposed strategies and offered alternative ideas and advice in adjusting the research method along the way. The combination of mentors from Design Informatics and Building Product Innovation was ideal for my research as the project is focused on these aspects. I found it challenging to follow a rigorous research plan as a design-based research process means that the results of experimentation continually redirect the outcome of the project. I learned to accept that it would not be possible to adequately research all aspects, as the potential related research topics could expand exponentially. Instead, I worked to focus the scope in order to produce a more substantial and detailed final result.

There are many ways in which this research could be developed further beyond the limitations of a Master's thesis. Testing the structural performance of the proposed reed bundles would be necessary to ensure their capability of withstanding the conditions on Texel Island. In order to verify how sustainable the proposed process is, calculations would need to be made to determine the energy efficiency of the harvesting and manufacturing machinery. The proposed process includes several machining and robotic processes. It is important to use clean energy sources and low emission machines to further the sustainability agenda. The lifespan of the proposed reed bundle system is difficult to predict, especially if the reed is maintained through periodic replacement of the outer layers. In order to determine this, long-term testing would be required. The robotic testing was focused on the use of a robotic arm as the best available method. It would be beneficial to consider other assembly options, such as the use of drones to expand the ability to access higher, difficult to reach areas. The development of a parametric computational model would be beneficial to generate the arrangement of reed components and the resulting building forms based on the specific site conditions.

The resulting system of reed-based components is compelling as it transforms the perception of a traditional material that is often viewed as weak, into one that performs multiple functions and produces sustainable architecture. I view the project as a first step towards rethinking the use of reed in architecture. While the nature observation structures proposed as a case study provide a simple program to allow focus on the development of the reed structure, given more time, I would look to develop more permanent, enclosed structures by adapting the same system. In practice this would enable much wider application of the system.

References

Garcia, M. J. (2019). *Discrete Flexibility: Computing Lightness in Architecture*. Architectural Design v89 n2 (March 2019), 70-77.

International Energy Agency and the United Nations Environment Programme (2018): *2018 Global Status Report: towards a zero-emission, efficient and resilient buildings and construction sector*.

Oxman, N. (2015). *Templating Design for Biology and Biology for Design*. Archit. Design, 85: 100-107.