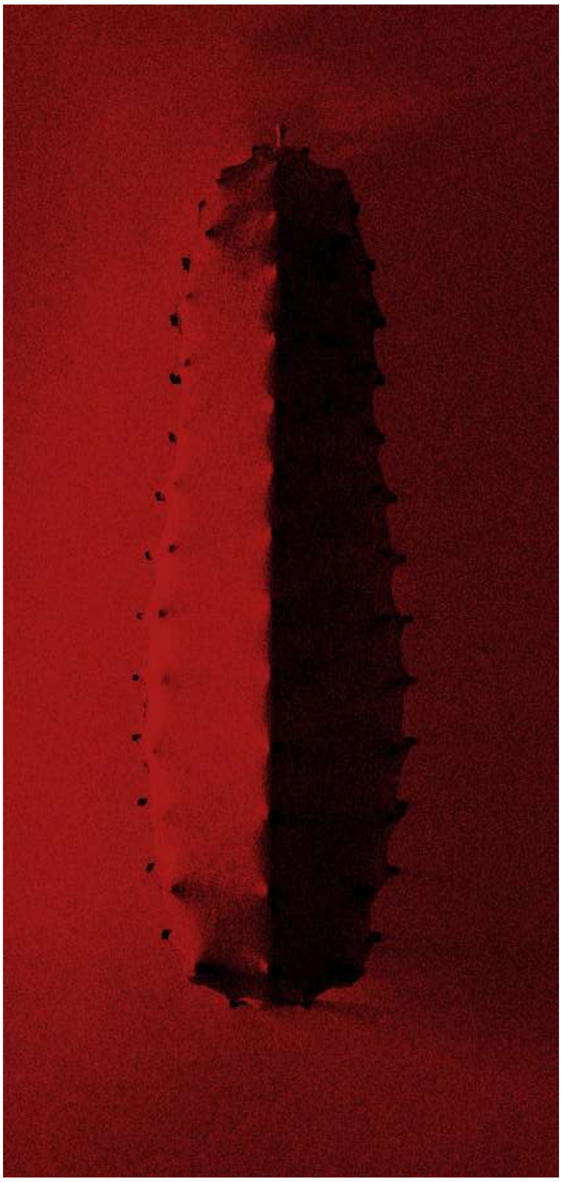
Architectural Muscle

The application of Kinetic Tensegrity Elements on Architectural Flesh



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Oskar Erenstedt

Personal narrative

During my adolescence I was enamoured with technical lego which laid a foundation for my love of problem solving and designing. Further interests within art and movies developed my sense of aesthetics and graphics. This culminated in the pursuit of architecture where I'm fascinated by the theoretics of the profession and am inspired by architectural movements such as metabolism and collectives such as Superstudio as well as modern writers like Rem Koolhaas.

Growing up in a digital age meant a sedentary lifestyle which negatively affected my health. Recently I have found a passion for exercising which in turn has improved both my mental and physical health. It seems the digital age has done similar damage to society at large and therefore the theme of movement is important to not just me but to all.

Abstract

Contemporary projects within kinetic architecture are primarily focused on the facades of the buildings and less so on the buildings' innards. Similarly this theme of outward focus penetrates the architectural profession as a whole leading to theories such as Architectural Flesh (Cruz, 2013) to emerge as a reaction to this trend.

Therefore, this thesis undertook the task of imbuing the flesh of the structure with kinetic elements to create a haptic relation between building and body and promoting a healthier mindset for both. In doing so the continuation of Architectural Flesh could be developed, Architectural Muscle.

To accomplish this the elements harness the movement of the inhabitants to aid the building's ventilation and create movement in the form of a pulse for the building. This lessens the energy expenditure of the building while evoking the sense of the building being alive, both which increases the sustainability of the building. One directly through lowering emissions, the other through an increased sense of empathy towards the building.

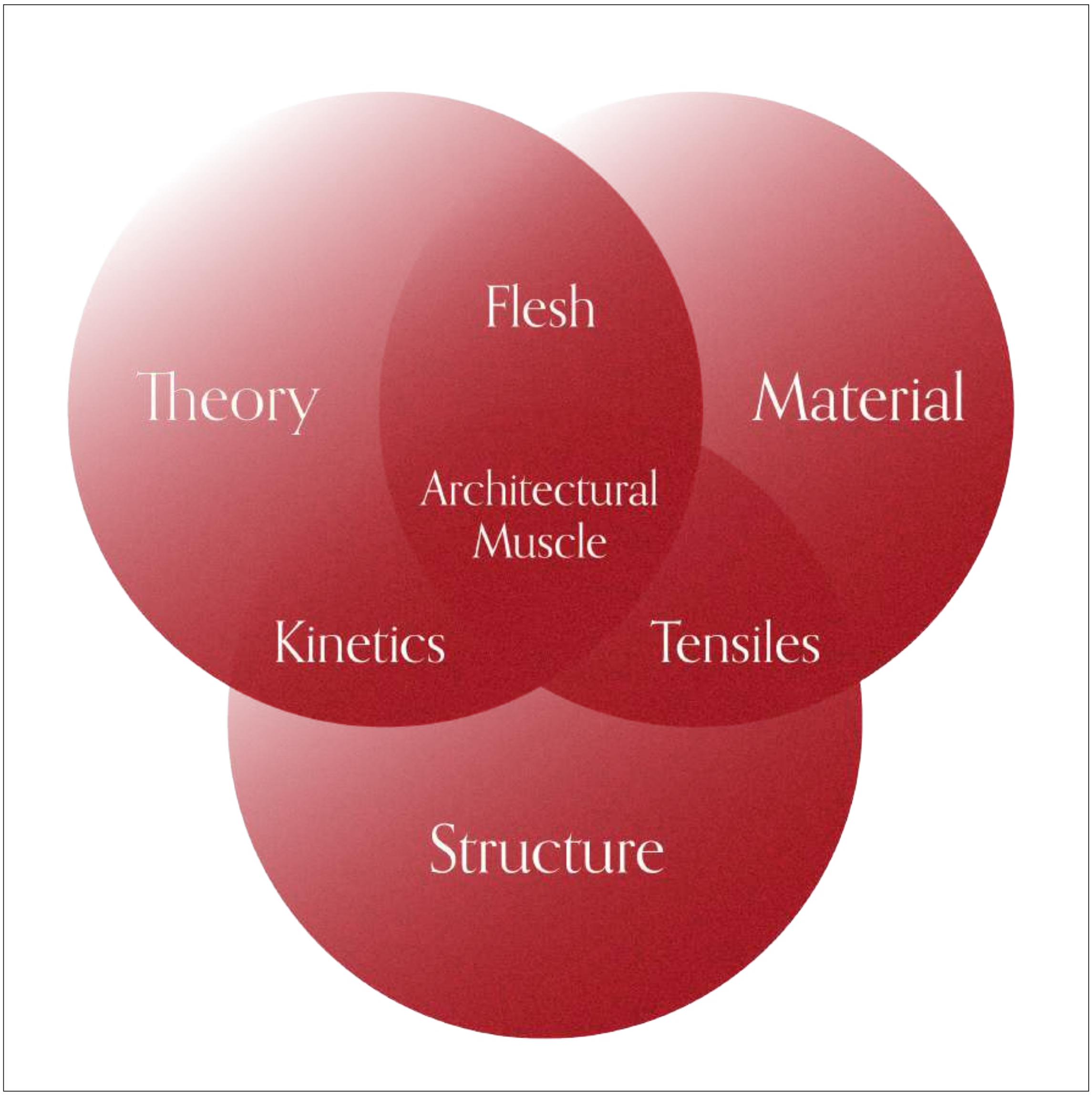
Physical modelling was integral to design a project which relies on several moving mechanisms to function. The main element, the muscle, was prototyped in accordance with human anatomy then placed into a platform mechanism which was repeated along a static spine with supporting functions. Enveloping this open air structure is a semi-transparent tensile fabric displaying the inner workings of the structure. Each step of this process has a prototype assigned to them to ensure their feasibility.

The result is a large structure spanning 140 meters with a width of 45 meters inhabiting a Body Movement Centre housing 14 exercise halls and with the capability to hold larger sporting events. The sense of motion is imbued throughout the building from the outer facade to the inner functions. Movement that creates an exchange between inhabitants and building invoking a symbiotic relationship that ensures both's longevity.

The resulting structure should be thought of as a prototype to be improved upon and inspired by. It is merely a stepping stone towards the unreal living, breathing and pulsating architecture that now is a little more real.

Keywords: Kinetic Architecture, Architectural Flesh, Tensile Architecture Architectural Muscle, Body,

Venn diagram of Themes, Sub Categories and Thesis Idea FIG. 1



II. Background

I've chosen three themes to centre my thesis around; Structure, Material and Theory. [FIG. 1] Where these themes intersect with each other they form sub categories that express what kind of references is needed to develop the thesis. Material theory connects the thesis to Marcos Cruz's theory of architectural flesh which will be instrumental for the project. Theoretical structure encapsulates kinetic structures which is what is applied to architectural flesh to develop the muscle. Structural material equates to elements carrying only tension such as fabrics to create tensile structures, these fabrics would be augmented with fleshy properties.

Combining all of these themes and categories would place the thesis in the centre where it tries to develop Architectural Muscle through research by design. The relevancy of the project will be discussed through the problems that will be put in relation to the themes and subcategories while the solutions primarily spawn from the subcategories.

Theory

Theoretically Cruz summarised it best when he wrote "*I believe that today's architecture has failed the body*" (2013, p.6) which is a sentiment that rings true within our profession and has been echoed in other texts such as Juhani Pallasmaa's book The Eyes of the Skin (2012). It is described by sociologist Richard Sennet as
"the sensory deprivation which seems to curse most modern buildings; the dullness, the monotony, and the tactile sterility which afflicts the urban environment" (1995, p.15) which insinuates a kind of numbness for our built environment, that goes beyond the mere practitioner but also the general public. The result is a sense that our surroundings are lifeless and lacks value which leads to a lack of motivation for preserving what we have and instead promotes building anew and wasting resources.

In Marcos Cruz's book *The Inhabitable Flesh of Architecture* (2013) he introduces a way of working with the relation of body and building through architectural flesh. It is understood as a wider embodiment of architectural skin while also being in opposition to the concept which he argues is reductive since it defines walls as mere membranes and "denying them the virtue of being thick." (Cruz, 2013, p.4)

The roofscape of Kunsthaus Graz

FIG. 2

Kunsthaus Graz, Austria (Cook, 2003)

Flesh can include many aspects of architecture which makes it less tangible but also enable a wider range of meanings than skin. One of these aspects is the actual materiality of flesh (Cruz, 2013). In Cruz's own projects such as *Hyperdermis / Walls for Communicating People* (1999) presented in the book this materiality is represented through latex. Further experimentation in the field of materiality is presented in the publication *Unpredictable Flesh* led by Malgorzata Zboinska (2019). It delves into the crafting of material imitating the properties of flesh such as transparency, haptic response and depth. Several experimentations are presented in this paper, *Hybrid Corpuscle* being one of them. It is created by layering several materials that exhibit varying physical, optical, textural and geometrical properties (2019). It is a very inspiring example of flesh-like materiality, form and voluminosity.

Another aspect of architectural flesh is the term *Neoplasm*, it describes something that is partly designed and partly living, thought of as an object that is formless. This separates it from the architectural term of *blobs* which insinuates a digital construct as a basis for the form, meaning it is represented within a geometric domain (Cruz, 2013). So far this concept is placed within an unreal framework as presented by Anthony Dunne and Fiona Raby in *Speculative Everything* (2013). This necessitates Cruz's references to also be speculative in nature except for one project which is the competition winning design of Peter Cook and Colin Fournier named *Kunsthaus Graz* in Austria (2003)(FIG. 2).

Early models of Kunsthaus Graz showed a rather formless, latex structure but because of the need to become more presentable to the jury the building eventually moved away from the associations of flesh by cladding it in the un-bodily blue material that is perspex. The argument put forth by Cruz is that even though the building lost plenty of its bodily functions it still keeps its status as an example of Neoplasmatic Architecture because of the animated media facade that makes up the skin of Kunsthaus Graz that becomes a self sufficient body with its own visual space that exhibits a sense of depth through its embedded luminosity. (2013)

A crucial concept in the book, and basis for Cruz's own project *Hyperdermis / Walls for Communicating People* (1999), is what he calls inhabitable interfaces which he describes as:

> *"Inhabitable interfaces should be understood as a new architectural flesh that is both real and virtually thick and in which an intense and interactive relationship between body and architecture can be established."*
> *(Cruz, 2013, p.69)*

Cruz goes on to list interactive elements such as in-wall seats, nooks and doors, deep walls, extruded windows, in walls shops, etc. Important to note is that these examples are very much real in contrast to neoplasms. While they do create a more embodied experience of a building, they are also simply passive, spatially interactive. They do not necessarily produce any reciprocal forces, no exchange of movement between body and architecture.

Structure

Within kinetic structures the use cases are largely limited to the climate control of a building through its protective shell, buildings such as The *Bund Finance Center* (Foster and Partners, Heatherwick Studio, 2017), *Al Bahar Towers* (Aedas Architects, 2012) and *One Ocean Pavilion* (SOMA, 2012). To a lesser extent do you see buildings that can expand their area of activity as is the case for *The Shed* (Diller Scofidio + Renfro, 2019) although this building could be thought of as two separate structures, one rigid and one movable. The potential of a building whose load bearing structure itself contains kinetic elements that react to the inhabitants of the building is not explored thoroughly enough.

There are explorations within the field of bodily movement and kinetic elements though. Several of them are found in the article *The Interrelationship Between Kinetic Architecture and Human Bodily Movement* (Sedky, 2021) which presents and discusses five different projects that translate human motion into kinetic elements. The paper focuses on the use of smart materials such as *Shape Memory Alloys* and *Shape Memory Polymers*, which are controlled digitally, or *kinetic sensors* as an interface between body and structure which all of the examples have in common.

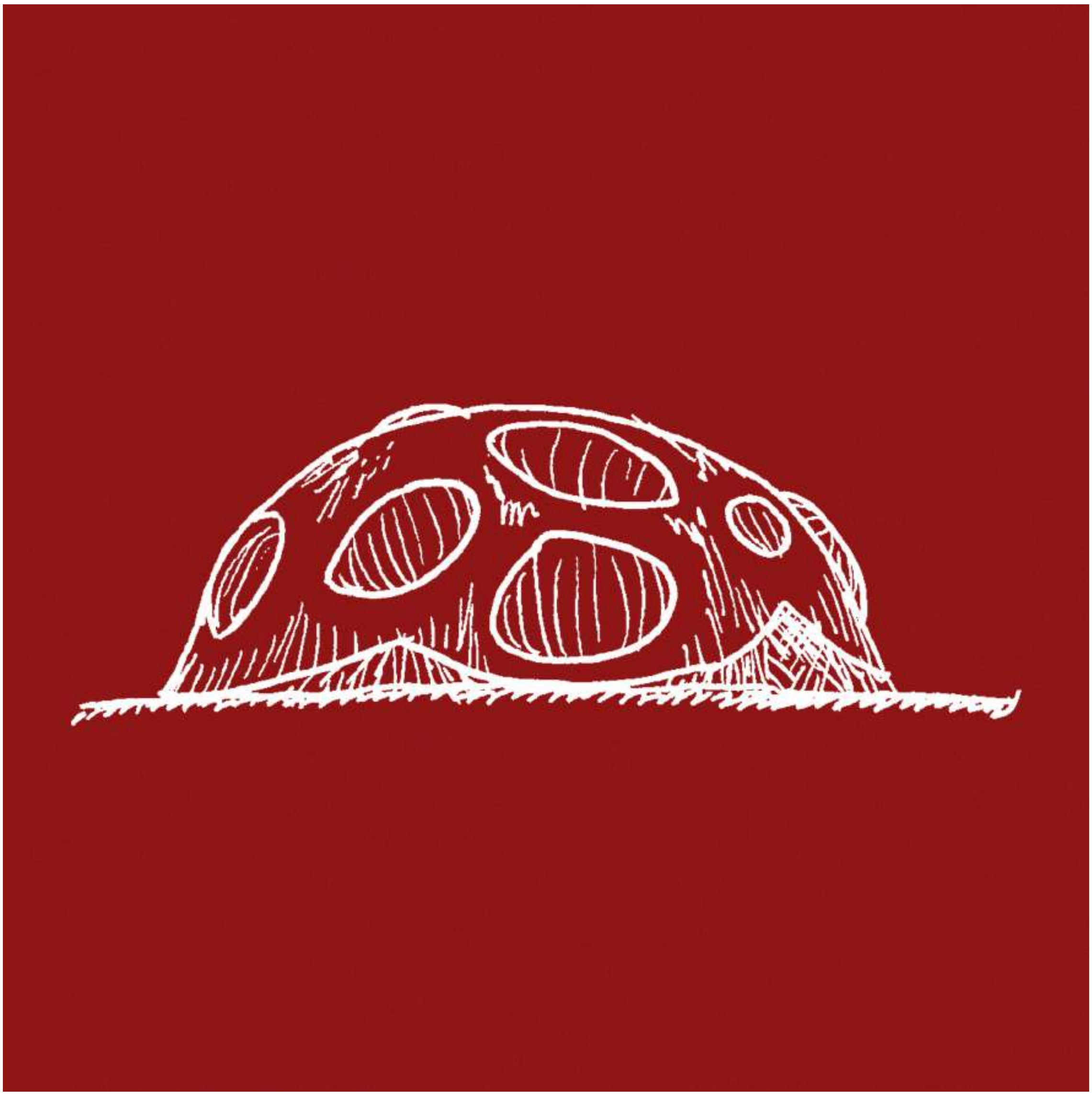
Integrating a digital interface that merely senses movement at a distance creates a layer of separation between body and structure and frankly conforms to an ocularcentric paradigm that shy away from haptic response, something Pallasmaa identifies as a great detriment which he thoroughly and convincingly argues in his book *The Eyes of the Skin* (2012). Therefore, the subject is approached using purely analog mechanisms that do not rely on external sources of electricity to function.

Material

To address the issue of material; Concrete is currently the most used material within the building sector and the most produced material in the world. It generates more emission per revenue dollar than any other material by several factors and as of 2017 concrete stood for 7% of the world's CO2 production (Malaga, 2023). By imbuing the concrete with steel it is able to be moulded into whatever form it needs to be, which is not necessarily the most efficient use of material. For example, elements such as beams that carry both tension and compression which leaves a lot of the material underutilised. If form instead would follow materiality, where materials carry either only tension or compression, there would be a reduction of both material volume and material waste (Chilton, 2010).

This is where the subcategory of tensile structures become relevant since they are lightweight and effectively make use of elements such as wires and fabric by putting them in a system of constant tension (Chilton, 2010). To exemplify the efficiency of tensile structures; the roof of *Denver International Airport* weighs as little as a tenth of any other roof system. It also reduced the cost of supports and foundation, required less mechanical equipment and simplified the drainage as well as saving energy through the usage of daylight, reflecting the heat from the sun and requiring less maintenance in general. Although it did cost more than a conventional opaque roof, but less than any roof with similar translucency (Berger, 1999).

FIG. 3



III. Project Description

The project handles and combines all the aforementioned issues, concepts and themes. By applying kinetic tensegrity elements to architectural flesh the flesh enters an active realm, where architecture does not just react passively and mimic the responsiveness of flesh but also the dynamic movement and functionality of muscle. Just like Cruz thought of his flesh as a wider embodiment of the concept of skin in architecture, the concept of *Architectural Muscle* is an active embodiment of flesh.

These muscles are placed within the load bearing structure of the building and absorb the weight of the inhabitants activating the muscles. The muscles function is to compress and expand to displace air and in doing so increase the draft of the natural ventilation. This renders the use of mechanical ventilation null. Keeping the connection analog throughout the structure, the inhabitable interface encompasses the whole area occupied by the users further blurring the line between body and building.

Covering this system of elements is the tensile structure made out of translucent fabric acting as the fascia rather than skin which brings about the perception of the building's innards being exposed. It is under this fascia we find the pulse of the building, generated by the muscles actions, a pulse that elicits motion through the play of light that stems from the building's inside. Just like Cruz points out in Kunsthaus Graz the facade becomes a self sufficient body.

Since body and movement is integral to the project the function should follow suit. Therefore the building occupies an activity centre where the increased flow of air from the muscles connects well to the need of the function. The bodies exerting force and creating heat gets a counterpart in the structure that exhales air creating a cooling effect.

An initial sketch of a building with muscles arbitrarily poking through the fabric of the facade can be seen in figure 3. Although the muscle elements themself are digitally created their sporadic orientation creates a kind of formless shape, adopting the qualities of a neoplasm.

Aims

The thesis explores the use of kinetic architecture beyond the application of facade elements and instead imbue it into the load bearing structure. This would aid in the building's climate control and reducing the energy expenditure needed to manage the building's functions.

The aim is to create a better mindfulness between body and building, in doing so creating an empathetic attitude towards the built. To accomplish this the project is placed within, while expanding upon, the theory of architectural flesh by the development of architectural muscle.

Furthermore, the project should integrate theoretics of tensile structure to efficiently utilise material properties to their fullest extent. It should also make use of fabrics with translucency to imitate the qualities of neoplasm presented in Kunsthaus Graz, a layered luminosity creating depth.

Delimitations

The exploration of kinetic elements will be limited to the muscles which is the primary mechanism being developed.

The thesis will not rely on digital interfaces such as sensors, motors or currents to actuate the muscles since this creates a reliance on external power sources and might add a layer of separation between body and building.

The project will not include any explorations of new materials. It will use existing research E.g. Malgorzata Zboinska's explorations of crafting material with flesh-like qualities. Any "new" materials will be exclusively speculative.

Research Questions

How can kinetic structures be used to effectivize the building's energy expenditure?

How can the application of architectural muscle through an analogue inhabitable interface increase the embodiment of the users?

How can the materiality and design of a building create a sense of flesh on both the micro and macro scales to evoke qualities of neoplasms?

Sustainability

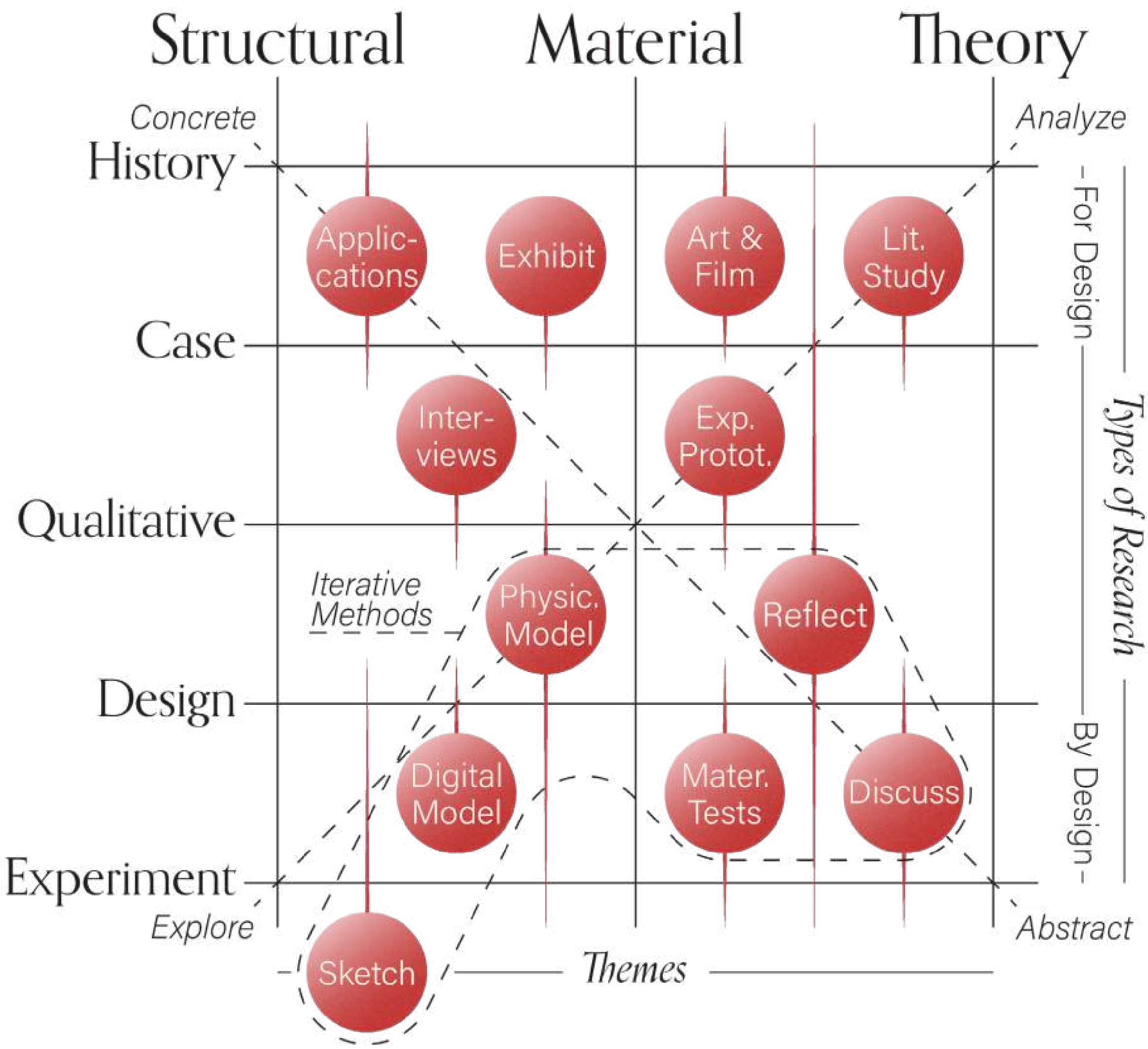
Since the added air flow that the muscle provides enables natural ventilation to handle the building's climate control it necessitates less energy expenditure. There is also no need for compensation from an external source of electricity to power a digital interface since the process is analog.

Additionally, the use of lightweight tensile structures will be a more effective use of material minimising the ecological impact. This is further reinforced by the fact that the existing building will act as the base on which the structure will be adhered meaning there is no need, except for possible reinforcements, to construct a foundation for the extension.

What is constructed being experienced as a neoplasm, something living, an organism in combination with the analog, inhabitable interface associating body and building creates an empathetic relation to the building, a caring attitude that ensures the longevity of the structure.

Choosing a Body Movement Centre as the function includes social sustainability through promoting a healthier lifestyle through movement and sports.

FIG. 4


Structural
Material
Theory
Concrete
Analyze
History
Case
Qualitative
Design
Experiment
Explore
Abstract
Applic-
cations
Exhibit
Art &
Film
Lit.
Study
Inter-
views
Exp.
Protot.
Iterative
Methods
Physic.
Model
Reflect
Digital
Model
Mater.
Tests
Discuss
Sketch
Themes
For Design
Types of Research
By Design

IV. Methods

To better position the methods used in relation to the work as well as conceptualizing and structuring the design research a diagram was made. [FIG. 4] The diagram is based on the text *Diagramming Design Research* (Wang, 2007) and will serve as a type of map to navigate the conceptual domain of the research.

The diagram is separated into the three major themes as well as five different types of research. Within this framework the paddles, which are representing methods, are placed in connection to the type of research and in relation to the themes. Both the themes and research types are ordered. The themes range from the more concrete structure to the more abstract theory while the research types span from research for design to research by design, analytical and explorative respectively.

Using this system of positioning within the diagram does not just structure the research but also suggests what to expect from the methods and their results.

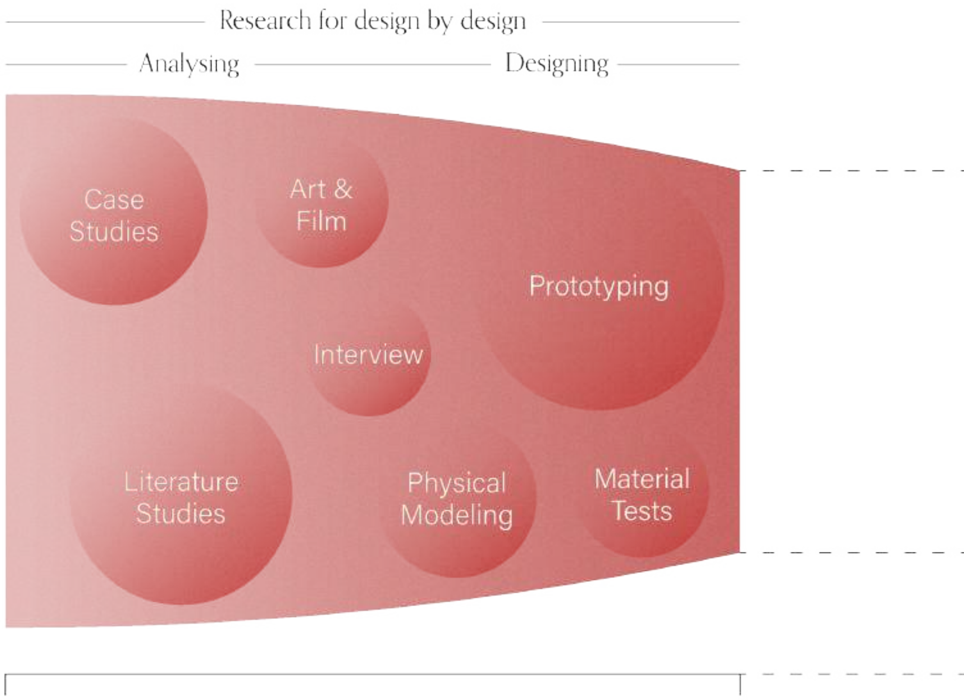
Currently the overarching framework of the thesis is placed within a *constructivist worldview* which means that the results will have a qualitative nature, placing emphasis on the discussion generated rather than any hard data. (Creswell, 2014)

Parts of the framing being qualitative could be seen as a given since design is utilized as the main propellent in the research. Although quantitative results might still be utilized to strengthen arguments made about the effectiveness of the muscles and the amount of air displaced by them. This would mostly be extracted through digital modeling using *Rhino* and *Grasshopper.*

Timeplan

Extrapolating the method diagram into a timeline [FIG. 5] with important milestones adds the layer of time to the mapping which allows for further understanding of the process at large. It is now possible to arrange when to use the methods, what the methods should deliver and what mindset to apply while using them. It will not merely visualise but be a tool itself to navigate.

For the ACE370 and ACE425 courses the aim is to gather and produce material that will act as a groundwork for the design research that will commence when the master thesis starts. This initial phase substantiates the research for design which will be a linear process. Although part of the methodology, namely physical modeling, material tests and prototyping, will itself be researched by design. Therefore an encompassing term for this phase would be research for design by design.



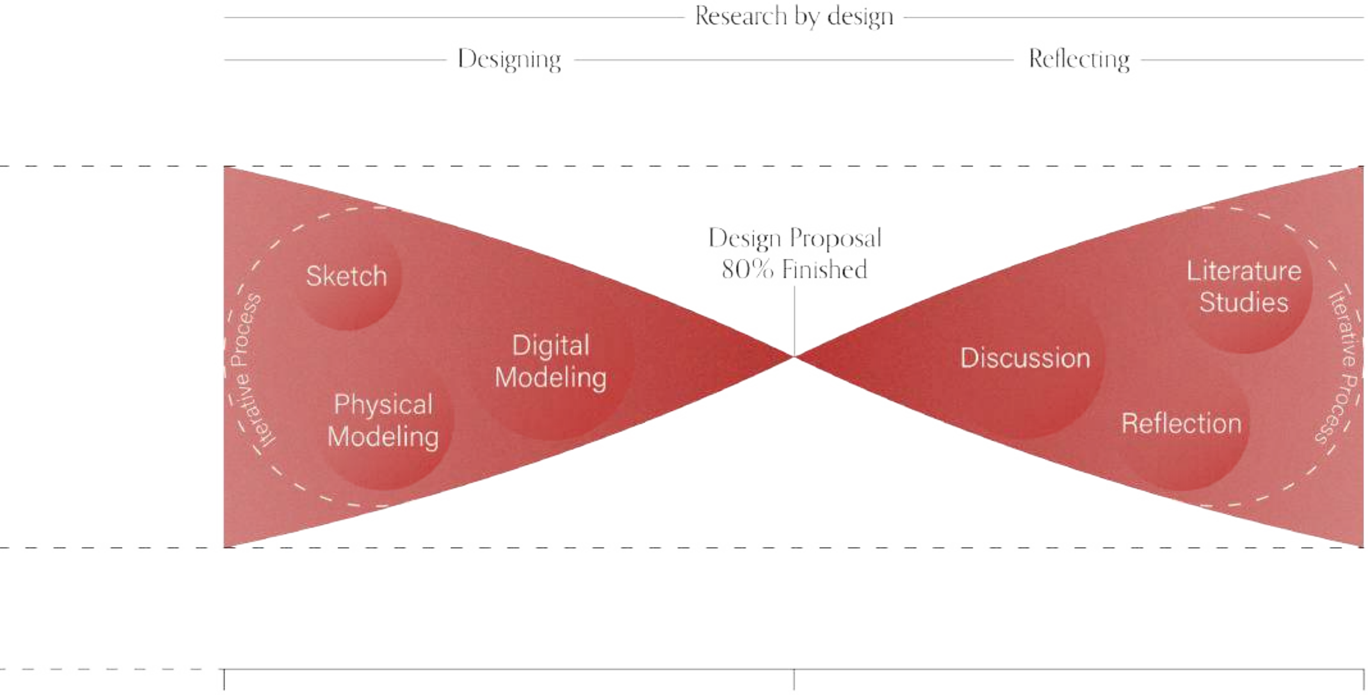
Start of ACE370 & ACE420

In the beginning phases of the project the scope will be wider and encompass a broader range of topics that connect to the three relevant themes from which the references have been chosen.

End of ACE370 & ACE420

At the end of the two courses the scope of the thesis should be reduced down to the essential concepts and theories. These subjects will all be represented within the prototype that acts as a proof of concept.

FIG. 4



Start of Master Thesis

In the beginning phases of the project the scope will be wider and encompass a broader range of topics that connect to the three relevant themes from which the references have been chosen.

Mid Review

Halfway through the thesis project a design proposal that distills and contains the essence of the thesis should be produced. This would be the most ample time to present the thesis and get feedback that encapsulates all the subjects.

Final Review

The results of the thesis will be exhibitioned at Chalmers as part of a bigger exhibition. Both the prototypes used to design the project as well as finished drawings will be displayed and accompanied with animations to display movement.

Muscles of the Human Torso

FIG. 5

Mashup of Plate 60 and 76 (N. H. Jacob, 1830)

V. Developing the Prototype

To develop the mechanics that are necessary for the design of the prototype inspiration had to be taken from human anatomy. Understanding the function of actual muscles will aid in the creation of the prototype of the architectural muscle. Furthermore, this both creates a foundation for the building's lifelike appearance as well as mimicking the inhabitants own structure. Enhancing the relationship between body and building, further increasing the embodiment of the users.

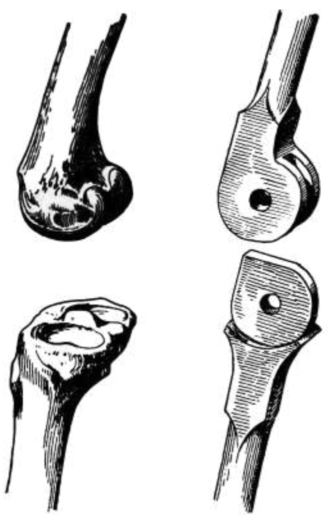


FIG. 6 Joint as mechanism (Viollet-le-Duc, 1879)

There is already a history of the body being used as an inspiration for dynamic designs since it is one of the more apparent uses of mechanics in nature. One example comes from the book *Histoire d'un dessinateur* by the french architect *Viollet-le-Duc* which illustrated the joint mechanism of the elbow as a mechanical joint in 1879 [FIG 6.]. This illustrates clearly how the skeletal system plays a big role in the functions of the body. Just as beams and pillars support the forces travelling through a building the bones and cartilage of the skeletal system supports the rest of the body. But that is not the only function of the skeletal system. By combining the skeletal system and muscular system the musculoskeletal system is created. The skeleton acts as points of attachment for the muscles; the force produced by contracting muscles can be utilised for movement. Bringing it back to mechanics, the bones act as levers while joints serve as fulcrums, when a muscle spans a joint and contracts the bones move (Gordon Betts, 2022).

As for the joints, there are different classifications which the joints fall into. This thesis will focus on the *synovial* joints which have the highest mobility of the joints. There are six types of these which fit within three subcategories, one of which is the hinge joint found in the elbow of the arm [A, FIG. 5]. It allows for movement in one plane putting it in the subcategory of the uniaxial joints (Gordon Betts, 2022).

Muscle tissue has a couple of key qualities that are instrumental to mimic within the design of my prototype to make it functional. Elasticity is the muscles ability to return to its original form when relaxed. Extensibility means it can stretch its length. In addition to these two there is also the property of contractility which means the muscle can shorten itself (Gordon Betts, 2022).

The functions that are important to mimic are best seen in the bicep [B, FIG. 7] and tricep [C, FIG. 7]. Rather, it is what these muscles achieve through their function that lead to the movement of the forearm. While both of their functions are to contract, their placement in relation to the bone structure and hinge joint dictates their use case. The bicep flexes the forearm while the tricep extends it (Gordon Betts, 2022).

Clearly then the placement of the muscles within the design is the primary decider of how the muscles will be actuated through the movement or how they themself actuate the movement.

Muscles of the Arm

FIG. 7

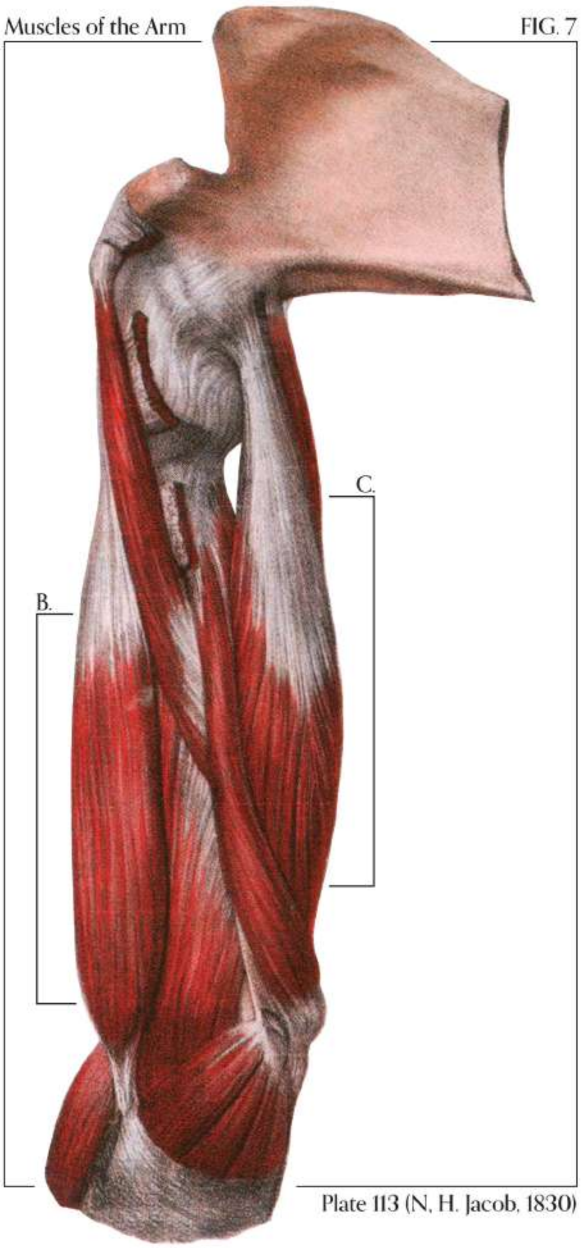


Plate 113 (N. H. Jacob, 1830)

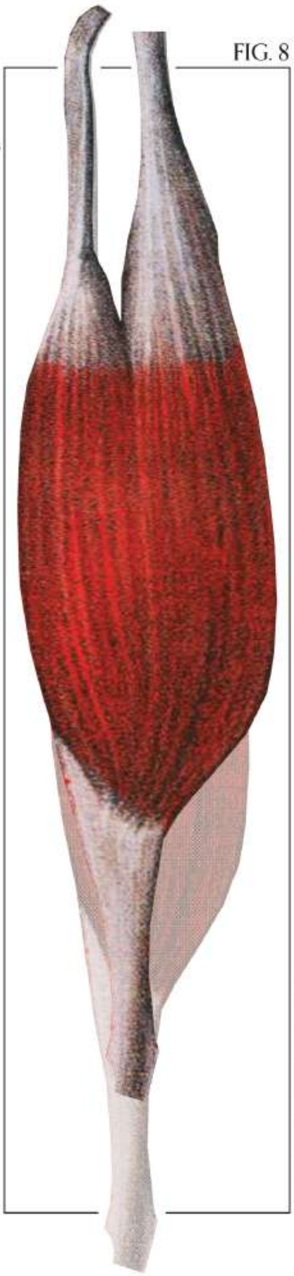


FIG. 8

Contraction of Bicep Brachii

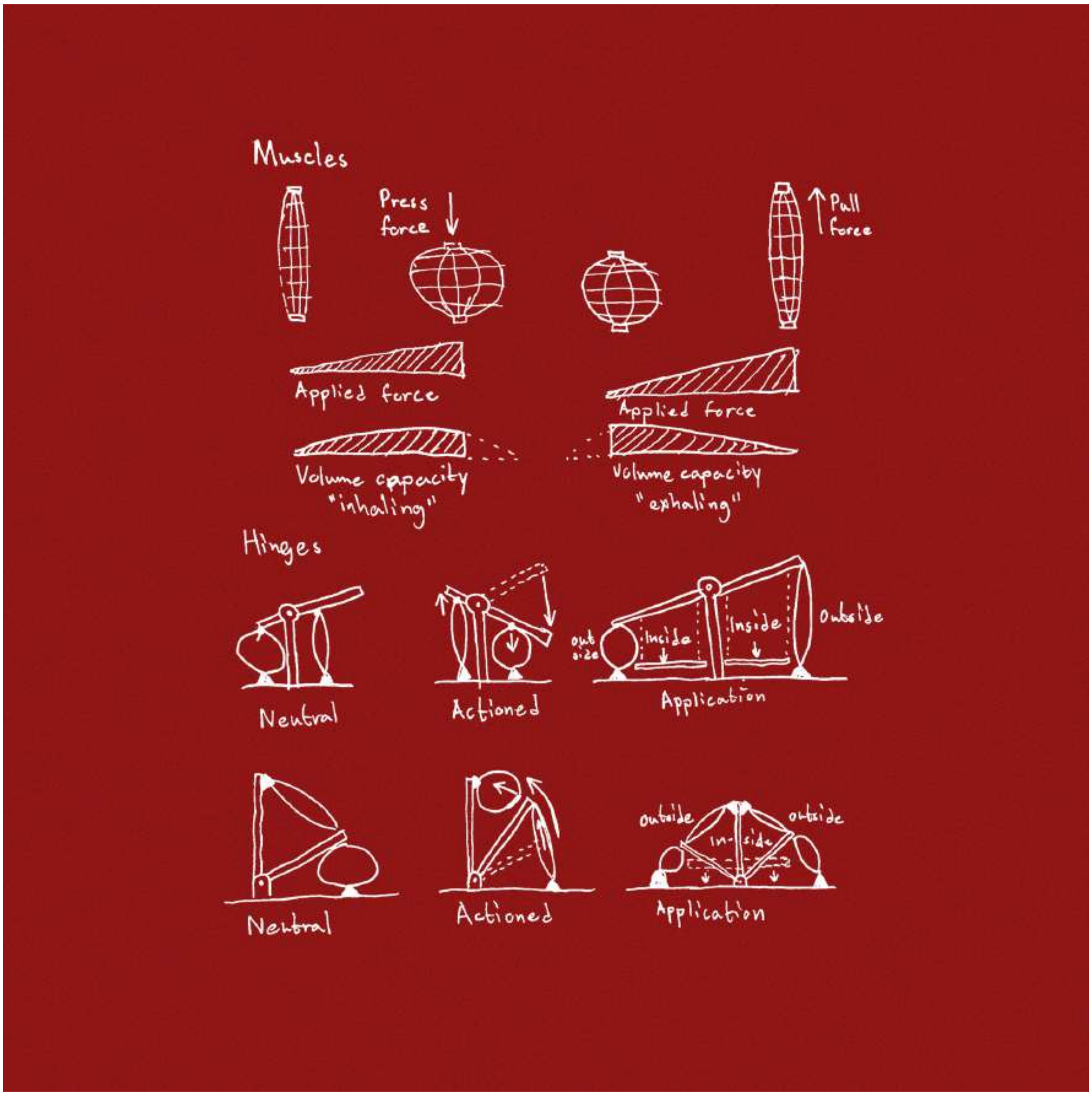
Plate III (N. H. Jacob, 1830)

As for the function there is a contradiction. In biology the muscles are the primary actuator themself, they provide the force by shortening their length. [FIG. 8] Within the project, to omit the need for external power sources, this force is produced by the users through the inhabitable interface.

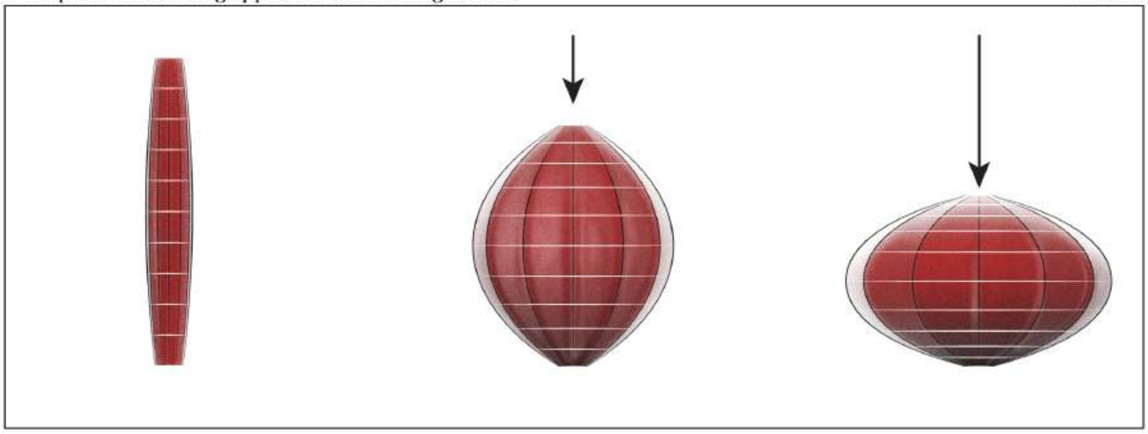
The biological muscles are densely packed with fibres to produce their force, since this is not the case for the prototyped muscle it is void of mass making it able to displace the air when contracted. In this sense it is closer related to the lungs which is categorised as an organ (Gordon Betts, 2022).

Although, if the embodiment of the inhabitants through the muscles is taken one step further; the users could be thought of as an extension of the muscle, the active part that produces the force. It is also important to factor in that this muscle element could have a different use case when applied to other projects. One of the more interesting use cases would be to infuse the muscles with biological material which could activate the muscles themself or employ them to transport sustenance needed to keep the material alive. A similar structure that would need this kind of addition is presented in a previous master thesis by *Karolina Bloch* called *Micro (2019)* where the facade is made out of living material.

These muscle elements are not supposed to be thought of as isolated entities. Instead they should be seen as either an extension of the inhabitants or as a stepping stone for future uses.


Muscles
Press force
Pull force
Applied force
Applied force
Volume capacity "inhaling"
Volume capacity "exhaling"
Hinges
Neutral
Actioned
Application
out side
Inside
Inside
Outside
Neutral
Actioned
Application
outside
outside
in-side

Principle of Force being applied to Contracting Muscle FIG. 10



Principle of Force being applied to Expanding Muscle FIG. 11

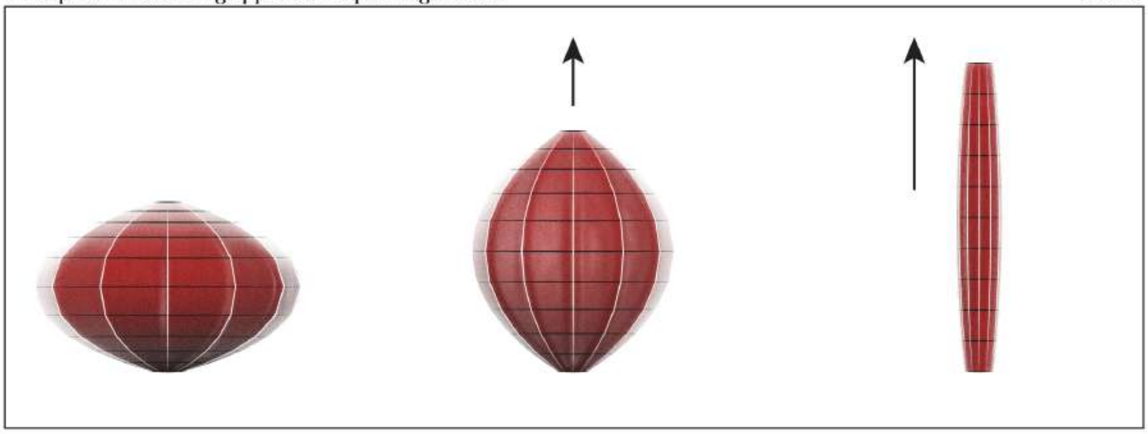


Figure 9 show sketches of the muscles design and their volumetric expansion as forces are applied to them. If the architectural muscles are meant to respond to force instead of producing it their design needs to be able to both handle the compressional force as well as the tensile force.

While relaxed the biological muscles can not withstand compressional forces since it acts like a bundle of strings. Therefore, there has to be two types of muscles to create an equilibrium on each side of the hinge, one that can handle compression and one that can handle tension. The application of force on these elements would have an inverse effect on the volume [FIG. 10 & 11].

Grasshopper Script for Parametrical Model

FIG. 12

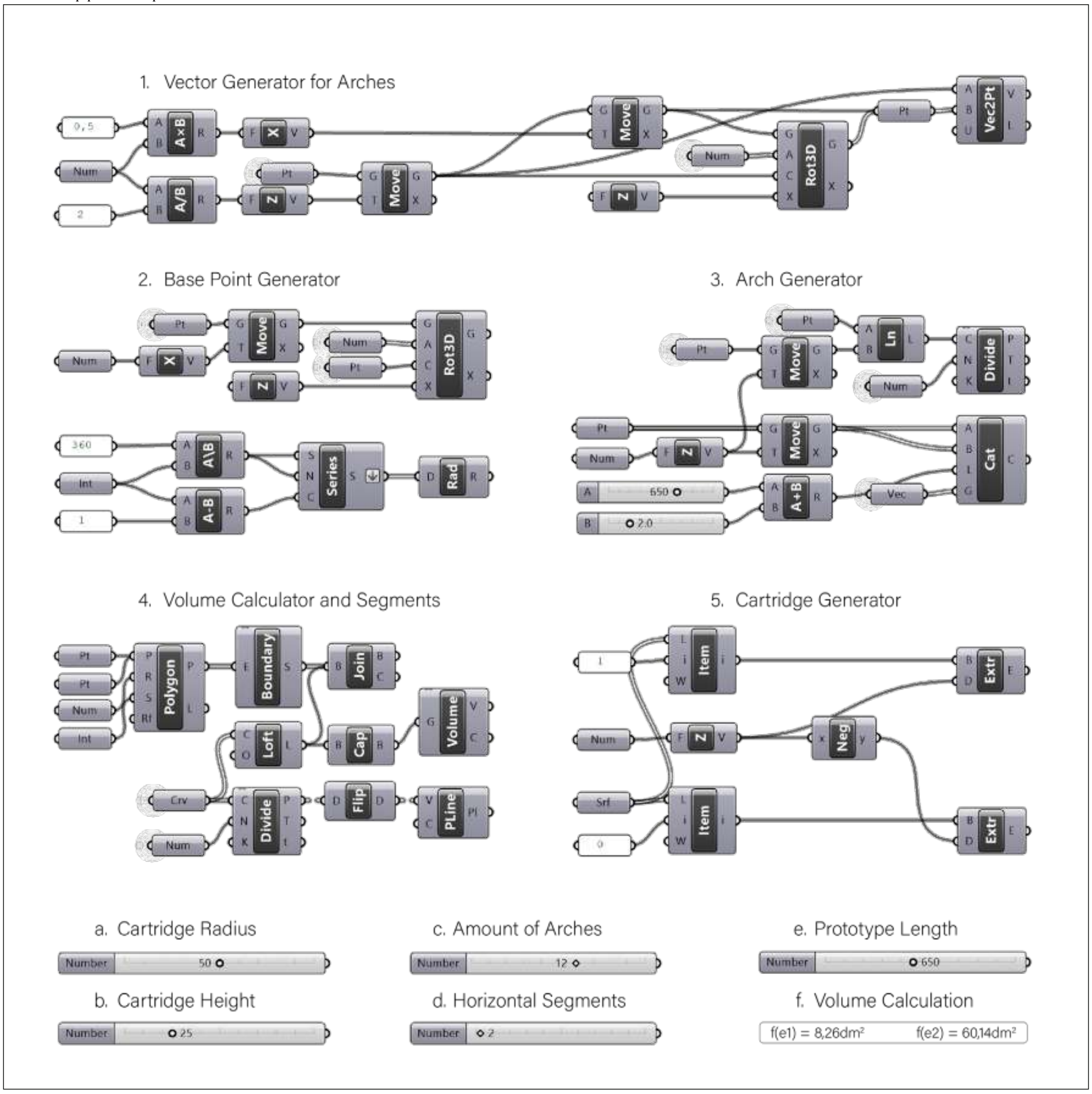
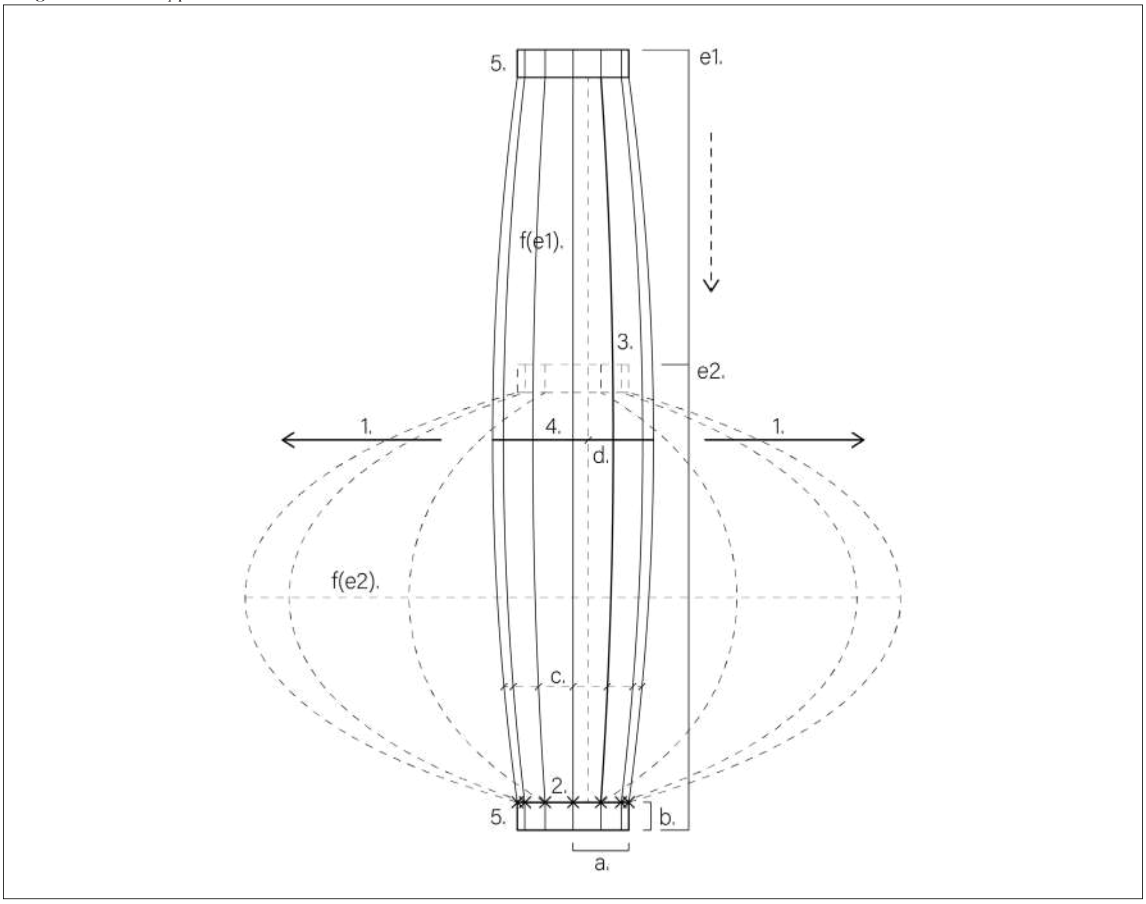


Diagram of Prototype Parameters FIG. 13



Digital Modeling

Using Grasshopper a model of the prototype with several input parameters was created to calculate the volumetric contstrains of the muscle. Inputting the static parameters creates the form of the prototype and by changing the active parameter of the prototype length [e1 - e2, FIG. 13] the volume changes accordingly. Between the maximum and minimum volume the ratio is greater than 1:7. With some further development of the script it can be used as a tool to swiftly create digital sketches. In doing so streamlining the process of calculating the air that is able to be displaced.

Physical Modeling

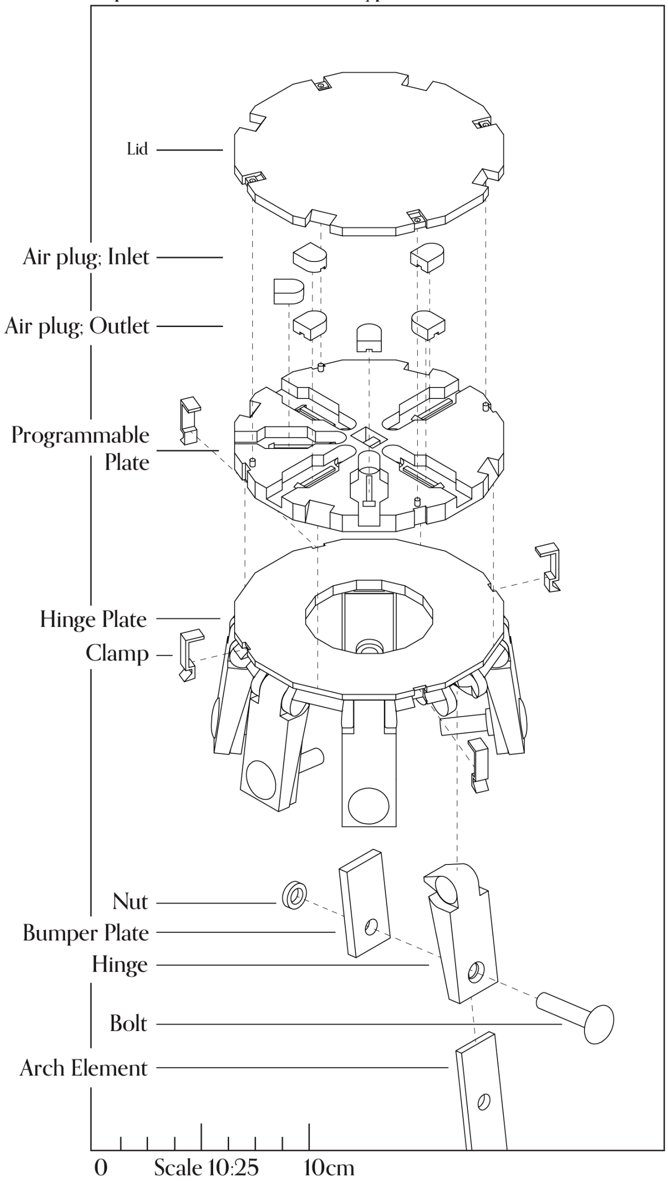
Exporting the simple Grasshopper model into Rhino allowed for a more detailed prototype to be designed and then manifested into a physical model through 3D printing.

Figure 14 shows an exploded isometric diagram of the cartridge that makes up each side of the muscle. This is where the input and output of air is handled to regulate the rate of contraction or expansion of the muscle.

By separating the inlet and outlets they can source the air from different sides of the building's envelope making it able to exhaust air from the inside and replenish air from the outside.

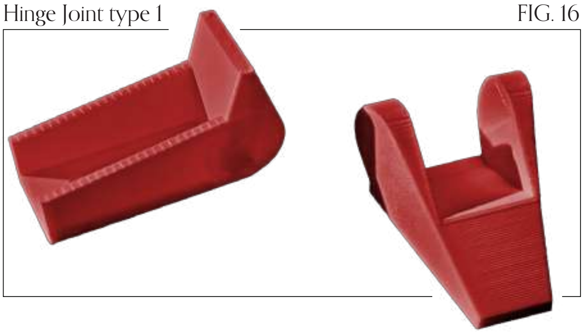
Connecting the cartridges are the arch elements that are fastened by the formerly mentioned hinge joints to keep the movement uniaxial.

Exploded Isometric of Prototype FIG. 14



One Way Air Valve Prototype FIG. 15

Hinge Joint type 1 FIG. 16



Hinge Joint type 2 FIG. 17

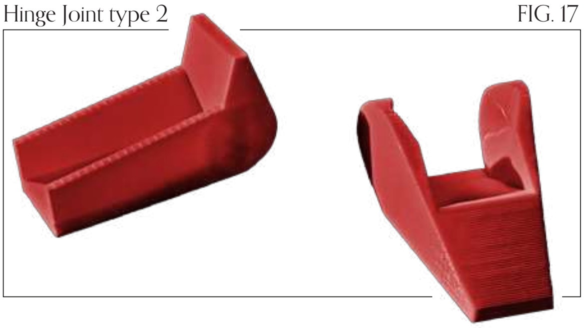


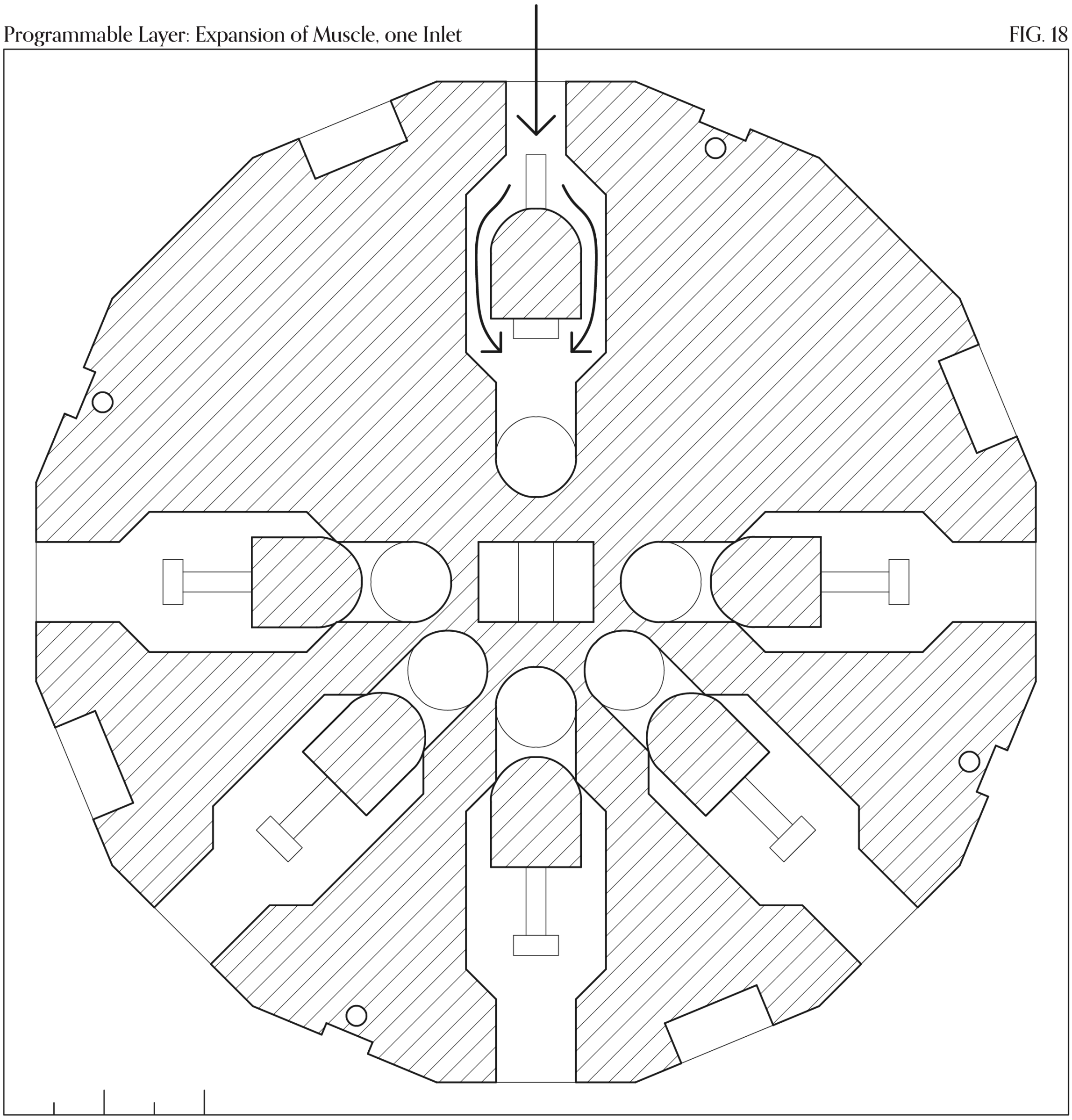
Figure 15 shows the prototype of the air inlet and outlet. The design is a check valve that only lets air pass through one side and not the other. When air passes from below the plug gets pushed upwards and seals the hole obstructing the path of the air. If air is let in from above the plug hits the lip on the rail letting air pass through. This principle is shown in further detail in figure 18 and 19.

The hinge joints were at first 3D printed into prototypes (FIG. 16 & 17). The first one, shown in figure 16, failed when connecting the two pieces, creating a crack in the material. A second one was produced, shown in figure 17, with a notch in the in the socket letting the hinge slide into place.

These prototypes reinforced the functionality of the mechanism involved in the final prototype of the muscle, introducing a bit of an iterative process.

Programmable Layer: Expansion of Muscle, one Inlet

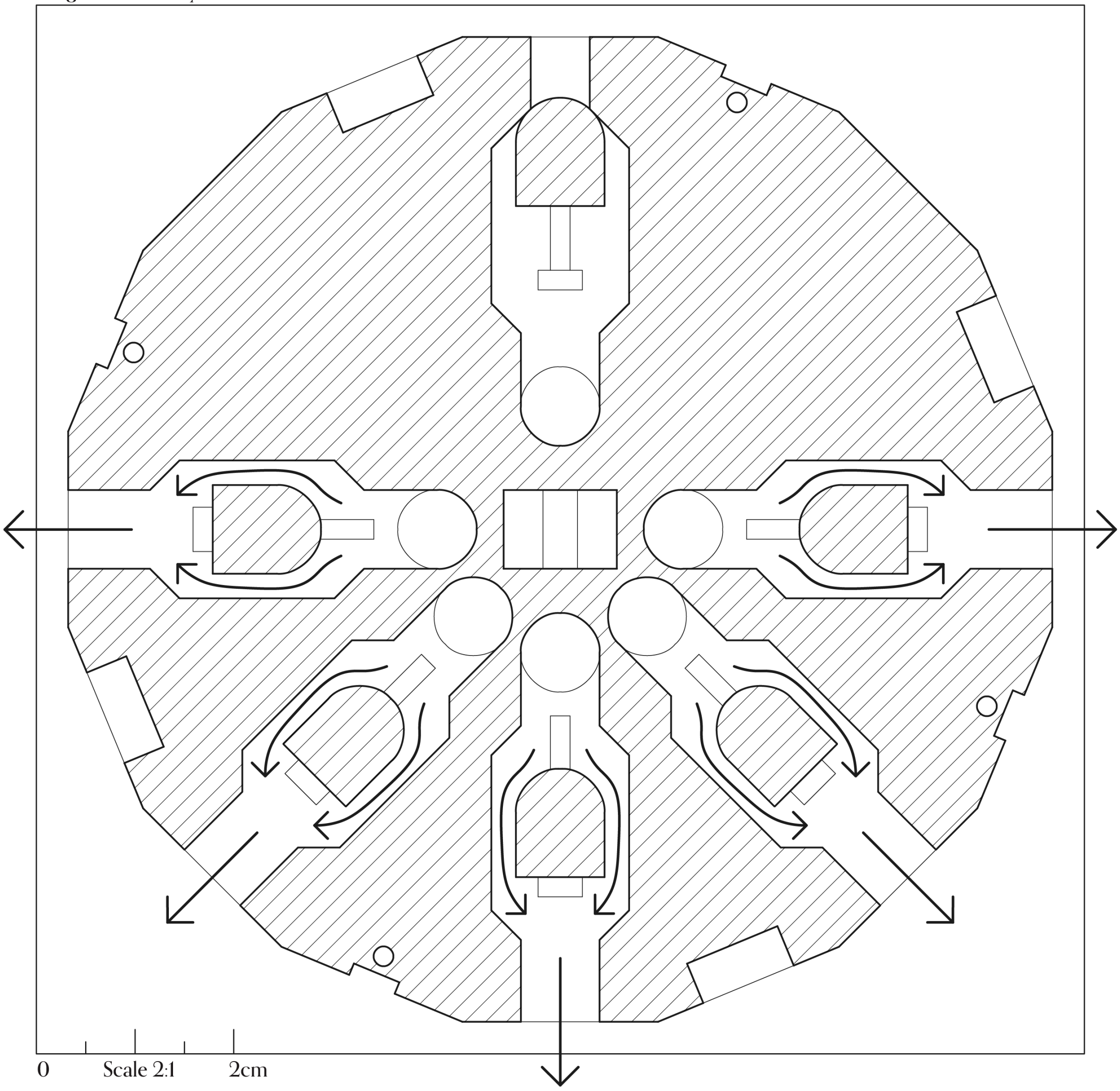
FIG. 18



0 Scale 2:1 2cm

Programmable Layer:: Contraction of Muscle, five Outlets

FIG. 19



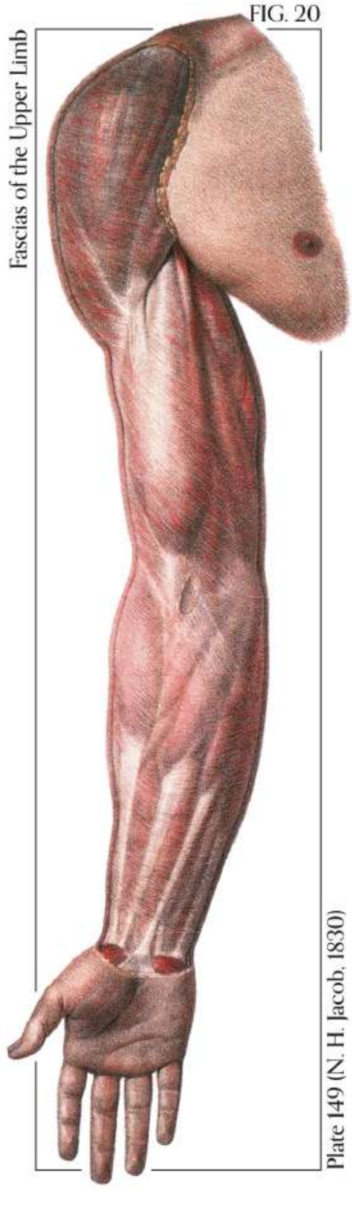
Material Tests

To be able to displace air the muscle needs to be covered in some kind of fabric. Once again human anatomy was a source of inspiration. In the human body the fascia [FIG. 20], a fibrous tissue, covers the muscle and skeletal system (Gordon Betts, 2022). It is translucent which means the underlying musculature is still showing making it the perfect analogy for the covering of the prototype as well as the extension at large.

The fascia is separated from the skin through the hypodermis making it more a part of the muscular system than the skin, an organ. This delineation might be technically unimportant but following the philosophy of architectural flesh, separating the fabric from skin and instead relating to the fascia would let the facade made out of muscles be a body of its own.

Liquid latex was used to mimic these qualities of the fascia, to replicate the materiality of projects such as Hyperdermis / Walls for Communicating People (Cruz, 1999) as well as availability of the material. Starting off, several sheets of latex were produced using different amounts of layers, kinds of pigments as well as separate kinds of brushes to research the properties that result [FIG. 24, 25 26, 27]. In general the brush seemed to give a more directional strength [FIG. 24, 25, 26] while three layers of brush strokes seemed to be the sweet spot, not too thin and probably thick enough. Adding pigment created a very strong hue [FIG. 26], the choice was made to move forwards with the appearance of raw latex.

FIG. 20



Latex Sleeve 1 FIG. 21

Latex Sleeve 2 FIG. 22

Latex Sleeve 3 FIG. 23

The first sleeve [FIG. 21] was made with four layers of latex. It was made as a sheet and then folded onto itself to form a sleeve. It was deemed too thick to stretch sufficiently enough and too small to fit the prototype.

The second sleeve [FIG. 22] was made with two layers of latex instead in the hopes of it being able to stretch easier. It was made by applying the latex directly onto a tube but was too thin and brittle to peel off fully.

Similar to the second one, the third one [FIG. 23] was also applied directly to a tube but with three layers of latex. Although it was easier to remove it also broke, possibly due to the manufacturing process

Latex Sheet 1

FIG. 24

First test sheet [FIG. 24] was made out of four layers of liquid latex applied with a brush. Defects can be seen where the brush accidentally caught on to underlying layers creating pimple-like spots. Overall the material was definitely stretchy but maybe needed a bit too much force to expand.

Latex Sheet 2

FIG. 25

The second sheet [FIG. 25] was made using the same methods as the first but now only by applying three layers of latex. The material properties seemed a lot better in terms of stretchiness. The difficulty of using latex also becomes apparent during this sample since the sheet folded in on itself and got stuck.

Latex Sheet 3

FIG. 26

Adding pigments to the sample while still using the brush to apply three layers made the strokes appear more clearly. The pigment itself did add a lot of colour to the sample and while looking decent when scanned the actual appearance was oversaturated. [FIG. 26]

Latex Sheet 4

FIG. 27

When using a foam roller instead of a brush the sheet became less directional. Although the foam roller did create a lot of air bubbles in the material which weakened the strength of the fabric. The strokes that can be hinted at in the other samples also evoke the sense of fibres which really fit the aesthetic of muscle. [FIG. 27]

Interview with Malgorzata Zboinska

Selected excerpts from interview with Co-Author of the project Unpredictable Flesh, presented as an exhibition at Färgfabriken in Stockholm, which handles interactive materiality in the architectural practice with themes of flesh and fleshiness.

Oskar Erenstedt

Can you tell me about yourself and your work here at Chalmers?

Malgarzata Zboinska

I am an architect by training and I have worked in architectural practice for over 10 years but I have divided my time between university work and practice. I moved over entirely to academia to conduct architectural research which I think is more exciting since practice is very pragmatic and conservative which means you can not try as many things as you can in research.

How did you come in contact with the concept of architectural flesh?

[Marco Cruz] had a book called Inhabitable Flesh of Architecture which made me interested in the notion and the way he termed it but i understood it more broadly in that I feel like the materiality of architecture is somehow lost in the standardisation and digitalisation dealing with a lot of constructs that are machine mass manufactured, it feels like we have lost our connection to the materials.
[...] So in [the project Unpredictable Flesh] that I was working on the aim was to activate our relation with architectural material by working with architectural expression means, which means activating things such as geometry, colour, texture and light. We worked through different prototyping methods creating different prototypes [FIG. 28 & 29] that were meant to explore how we could create these constructs that invite people to touch and interact with them. Some pieces were also equipped with digital devices with sensors that respond to touch. Things such as lights and vibrating motors were embedded in some of the prototypes so you could discover through interaction with a piece.

FIG. 28

Hybrid Corpscule booth from Unpredictable Flesh Exhibiton (Zboinska, M., et al. 2019)

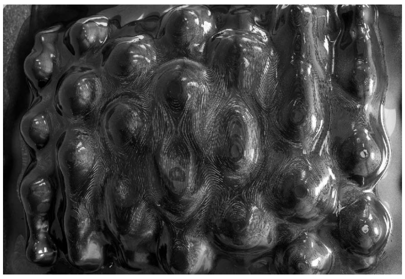
O.E.

While on the topic of your research project, Unpredictable Flesh, what was the reaction towards the constructs during the exhibition? Was it disgust, excitement?

M.Z.

I think people were very excited, the intent was to not work with the notion of disgust as Cruz for example. For me it was more focused on the aesthetics of it, my observation was that people actually wanted to get closer and touch the pieces to understand what kind of material it was. Using the sense of sight was used to identify that it looked different than a normal object so they wanted to touch to check what it was. They said that it looked soft but when touched it was hard so the element of surprise occurred. As for the interactive pieces with electronics the people were pleasantly surprised to discover the designed scheme of interaction.
[...] I felt that people were interested and curious about what the artifacts were and how they worked and wanted to get a sense of the material, they were not satisfied with just looking at it. In that sense it was working as intended.

FIG. 29



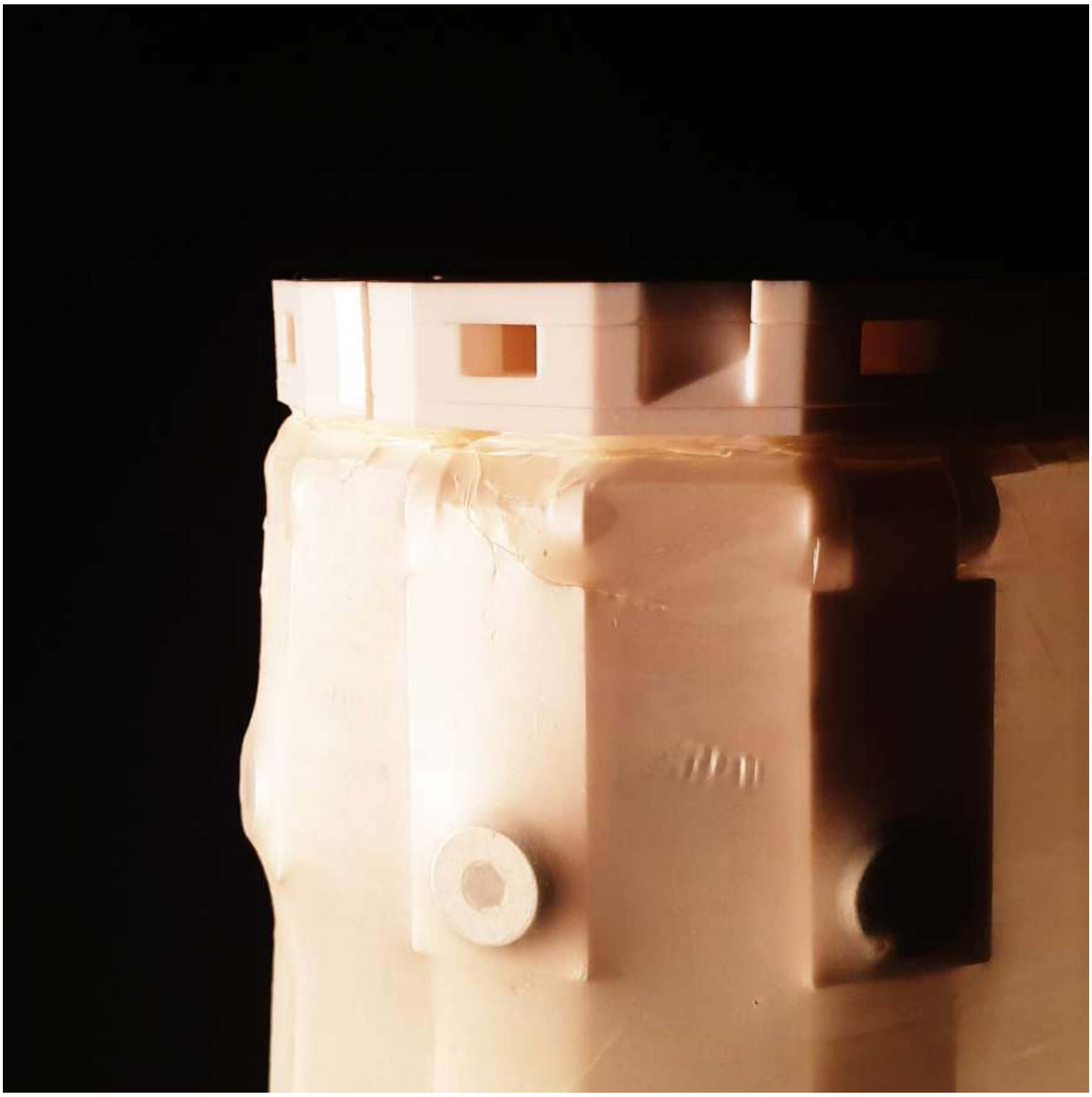
Bulbous Flesh, Unpredictable Flesh (Zboinska, M., et al. 2019)

I was curious what you think would happen if an artifact is placed in a cityscape rather than an art gallery where people are predisposed to curiosity. Do you think this setting could entail a stronger sense of disgust?

I think it is a matter of the design of the artifacts, what kind of design mediums are used, what the material looks like and if you intend for it to be treated as a provocation or if it is supposed to organically grow with the local community and be easily acceptable by the people, so it depends on your strategy for the design proposal. If you want to shock people you might generate disgust but over time people get used to things. There might be a shorter time frame of disgust that slowly goes towards acceptance.

Summarising the learnings from the interview it inspires one to take advantage of the academic privilege of exploration. Teachings from the exhibition are that people's interest do pique when confronted with an odd object, compelling them to touch and interact with it. Having intent in the design approach of the project is critical to make sure that the expected reaction is elicited.

Close up of Prototype showing Cartridge and Hinges FIG. 30

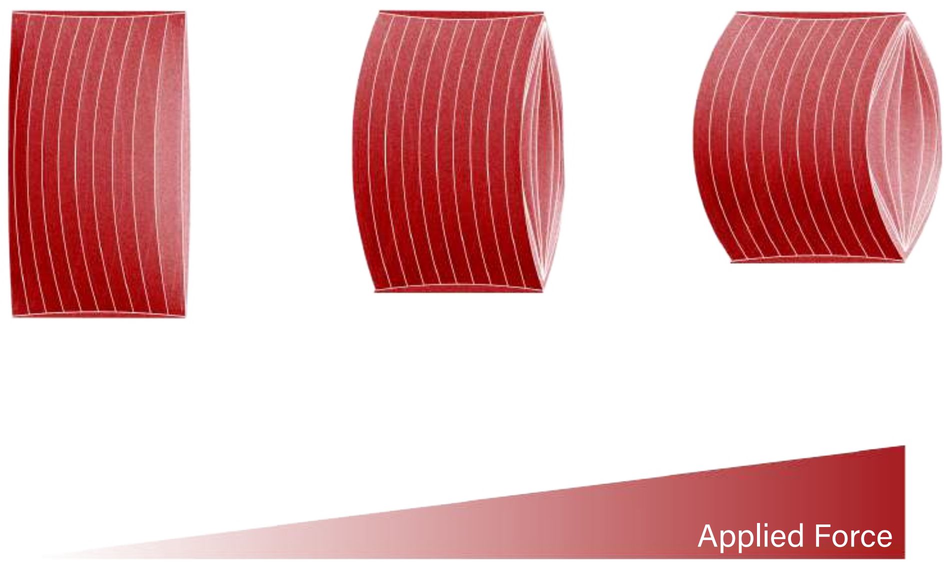


Full Prototype Backlit FIG. 31

The final prototype of the muscle was a success even though it did not quite reach the expected result. The force needed to compress the muscle is quite high and the latex, while stretchy enough, does deform slightly after stretching which creates scaring. Further improvements to the muscles fabric is needed.

The silver lining is that the pneumatic effects of the muscle are working and are noticeable. Air clearly gets sucked in when enough weight is put on the prototype, and when let go off the air exhales. If the weight can be applied evenly and the fabric is able to deform enough the muscle would work as intended.

FIG. 32



Further Prototype Iteration

Further iterations of the muscle [FIG. 32] were developed digitally to amend these discrepancies which means a different design making it a wall element instead of the more pillar-like first iteration. The reason for the redesign is the previously mentioned intention of the muscle to be the barrier between inside and outside making it able to insert and extract air respectively.

While the two prototypes' vertical cross sections are very alike the difference is the horizontal cross section where the original prototype expands in all directions while the wall prototype mainly expands on two sides, making up for the difference.

The second iteration's design method starts off the same as the first with a digital model from which the requirements for the physical model can be extracted. Specifically what is learned is the amount of stretch needed for the supposed fabric between the minimum and maximum action of the muscle. By measuring the length of the cross section's circumference between these two states we get a measure of the ratio needed. In the original prototype the ratio was 4,5 times while this new wall prototype expands by 2 times the circumference.

These figures do give some hope about the muscles materiality. Initially after the first material tests it seemed like the amount of stretch needed for the muscle would be too much but with the redesign it seems to be a more workable figure.

Building Design

With the muscle prototype sorted the foundation for the building needs to be developed. Therefore some decisions have to be made about what kind of function the building should encapsulate. Since the muscles purpose is to increase airflow this should aid the function. There is also a theme of the body and movement throughout the project as a whole. From these factors the idea of a Training Facility, a Body Movement Centre, emerges.

The muscles should be placed between the inside and outside of the building to allow for extraction of outside air which can later be expelled on the inside. This suits the needs of a training facility well. Although the muscles are placed at the facade of the building they most likely can not make up the entirety of the facade since they will have gaps between them and sensitive moving parts. A protective layer of tensile fabric will be covering the muscles to protect the muscles from the elements while still having enough milky transparency to showcase the muscles themselves, this will be the fascia of the building.

Since the muscles' purpose is to react to the inhabitants of the building, the people's weight is what should act on the muscles. Ironically, when performing movement based activities one wants a stable and secure ground to stand on, except for trampoline based activities, which means that the muscles should not react on every step provided by the inhibitors but rather their overall weight attribution. This would also provide a more constant rate of airflow and less stress on the muscles than a more explosive action creating smaller bursts of air and more erratic force.

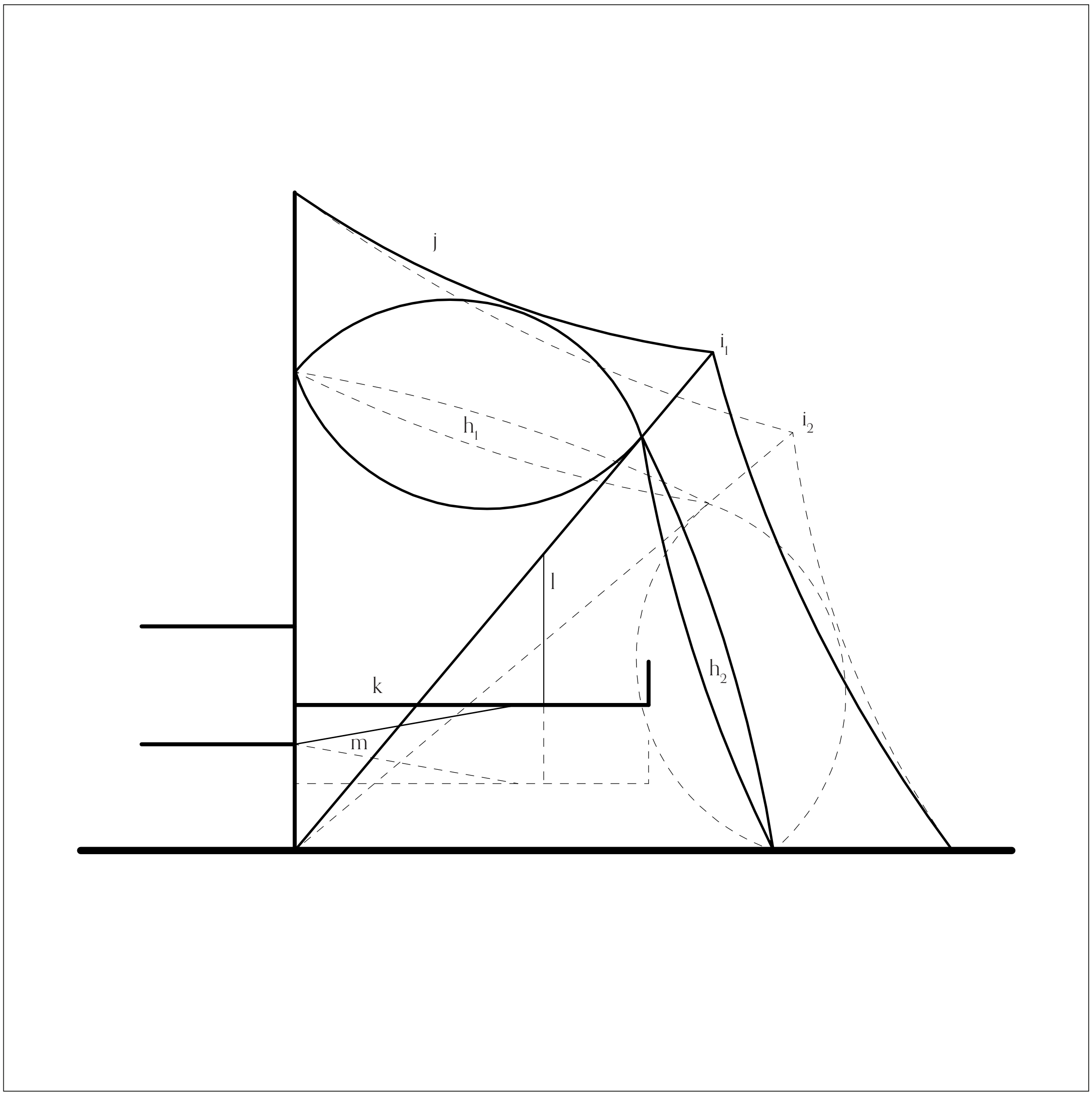
This lends itself for the muscles to be connected to a bigger platform area where people enter and exit periodically. Very much like a training hall where activities such as yoga, or martial art classes can take place. This necessitates several of these platforms, or halls, to be present since it would allow for multiple forms of exercise to be performed simultaneously.

Even though, or maybe particularly because, these platforms will not be able to be encapsulated by firewalls, there needs to be a way to continuously enter and exit the hall. This will be limited to just one passage, even though two would be possible. This is to ensure that there is always a way to get off the platform in case of emergencies or the occasional toilet break.

Lastly there is the case of where these essentials such as toilets and changing rooms as well as administrative facilities should be placed. For this purpose a static part of the building will be necessary, this will also be where the muscles get a vertical attachment point to adhere to. In addition all of the vertical communications should be situated in this static part as well as the entrance.

The building will be a Body Movement Centre
The muscles placement should efficiently maximise airflow
The muscles will be placed in the barrier between inside and outside
There will be a transparent tensile fabric encapsulating the building
The peoples weight should be the contributor to the muscles' movement
The floor interface connected to the muscles should itself be rigid
There will be several of these platforms to allow for simultaneous exercises
There needs to be a way to continuously enter and exit the platforms
The essential facilities as well as vertical communications and entrance will be placed in a static structure within the building

FIG. 33



Physical Prototype FIG. 34

Platform Prototype

Taking in account all of these necessities the prototyping for the platform mechanism could begin. There are a couple of main parts that are essential for the mechanism;

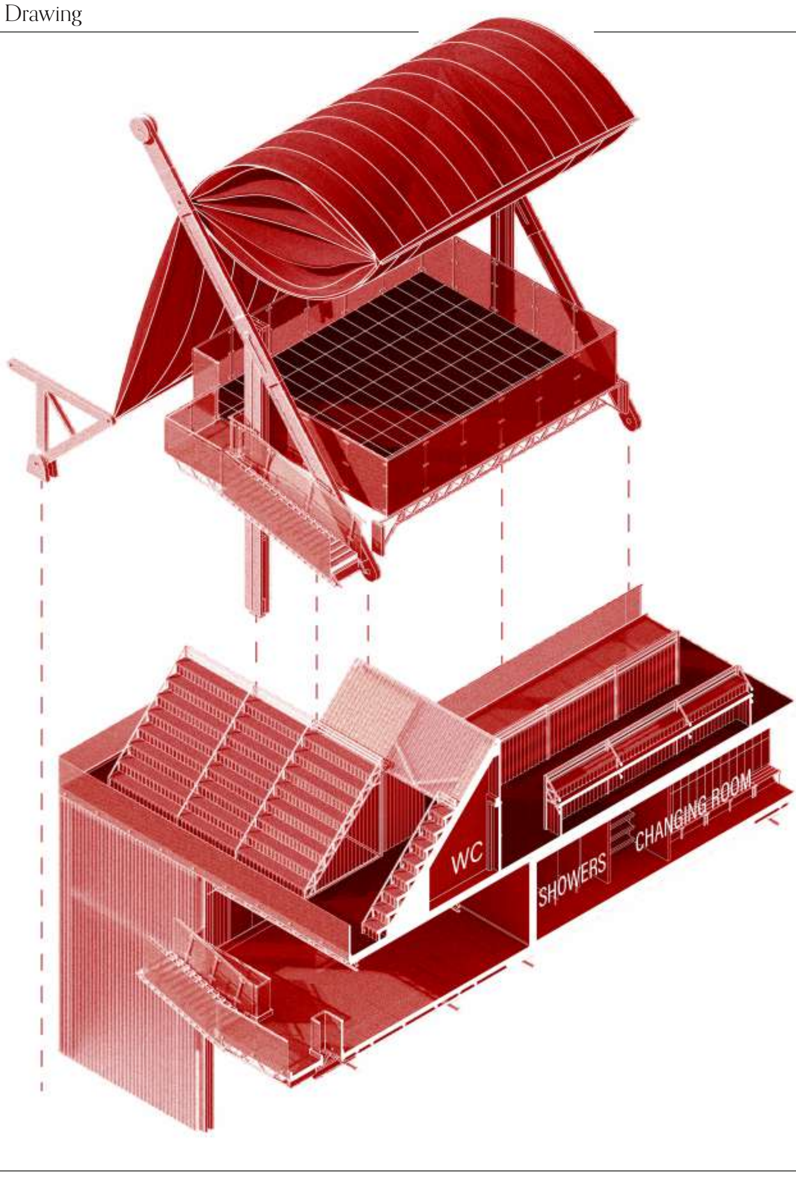
Firstly the muscles [FIG. 33, h_1 & h_2] are symmetrically connected to an arm [i] which is able to move when force is applied. The arms position is asymmetrical when at rest [i_1]. While the arm is maximally extended [FIG. 33, i_2] the relation is inverted, meaning one muscle inhales [FIG. 33, h_2 when $i_1 > i_2$] while the other exhales [FIG. 33, h_1 when $i_1 > i_2$]. By putting one on top and the other on the bottom they can more efficiently cooperate to create a draft by inhaling stale air from above and pull fresh air from below.

The outer fascia [FIG. 33, j] is connected to the same elements but further away from the hinge, ensuring it does not interact with the muscle directly. Since it is connected to the outer part of the moving arm the tensile fabric will move as well. This ensures that the movement of the building is not hidden from passers by and the theme of movement is clear throughout every part of the building.

The platform [FIG. 33, k] is being supported only from the muscle arm while stabilized horizontally by a rail mechanism [FIG. 33, l] locking it into a vertical movement only. While people inhabit the platform it applies a force on the arm and lowers slowly throughout the training sessions. By connecting the platform with a variable stair [FIG. 33, m] whose steps align at all times there is always a passage to exit the platform if needed. This variability is entirely mechanical, the steps are locked in horizontally due to their inability to tilt, the rail they are attached to makes them able to vertically move.

Exploded Module Drawing

FIG. 35



These combined makes up the mechanical prototype [FIG. 34] and shows the concept behind the exercise halls physically. This first physical prototype still needs to be further developed to fix some problems when it comes to friction and dimensioning. But still the feasibility is showcased fairly well.

The Module

With the prototype for the platform modelled, as well as the updated muscle design, it can be extruded into a full fledged module. [FIG. 35]

Additional qualities that have been added when modelling are the needed railings for the platforms as well as a viewing platform situated one floor up which gives a place for family and friends to spectate ongoing activities. On this floor smaller commercial businesses can be placed such as kiosks where visitors can buy a coffee or baked goods for a better spectator experience.

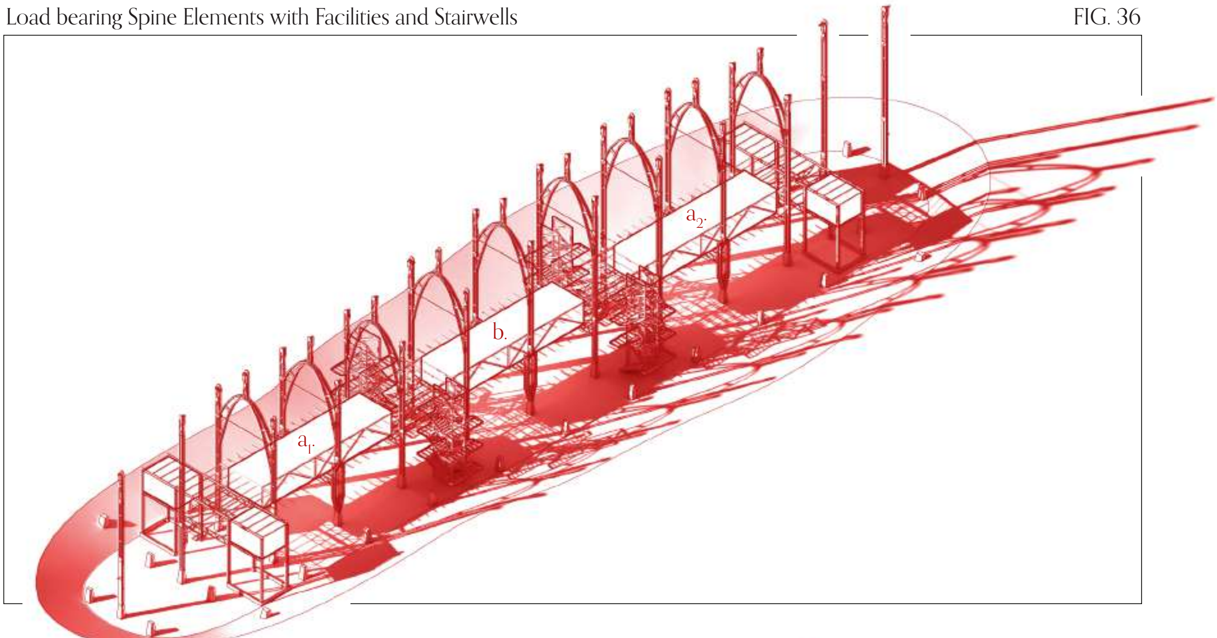
Below this viewing platform there is space for supporting facilities to the platforms such as bathrooms, back office, changing rooms and storage for exercise equipment.

The two different use cases for the floors make it reasonable to divide them into a public floor accessible for visitors and a private exercise floor with restricted access for paying members of the centre. The central area occupying these two floors will be the building's spine.

Pictured in figure 35's bottom left corner are accessory rooms where miscellaneous activities can take place such as massages, personal training guidance or regular storage. These vertical towers are also replaced by staircases at some points to provide vertical communication between the floors.

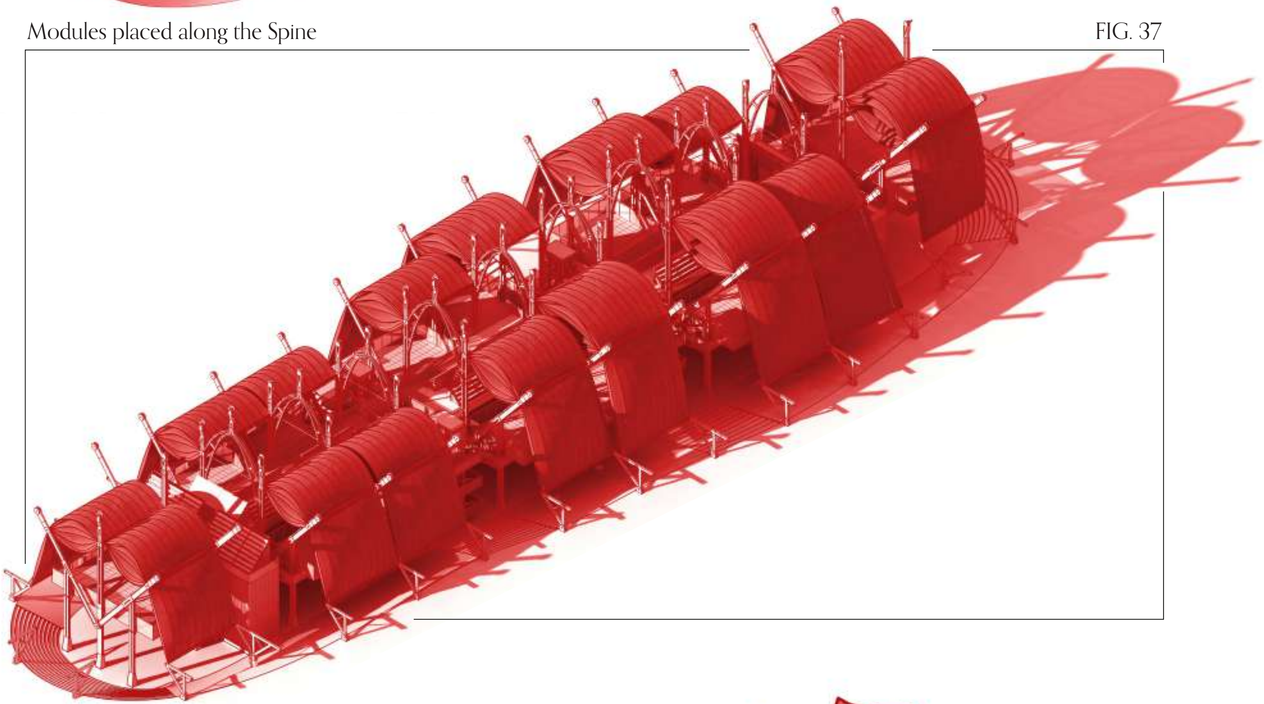
Load bearing Spine Elements with Facilities and Stairwells

FIG. 36



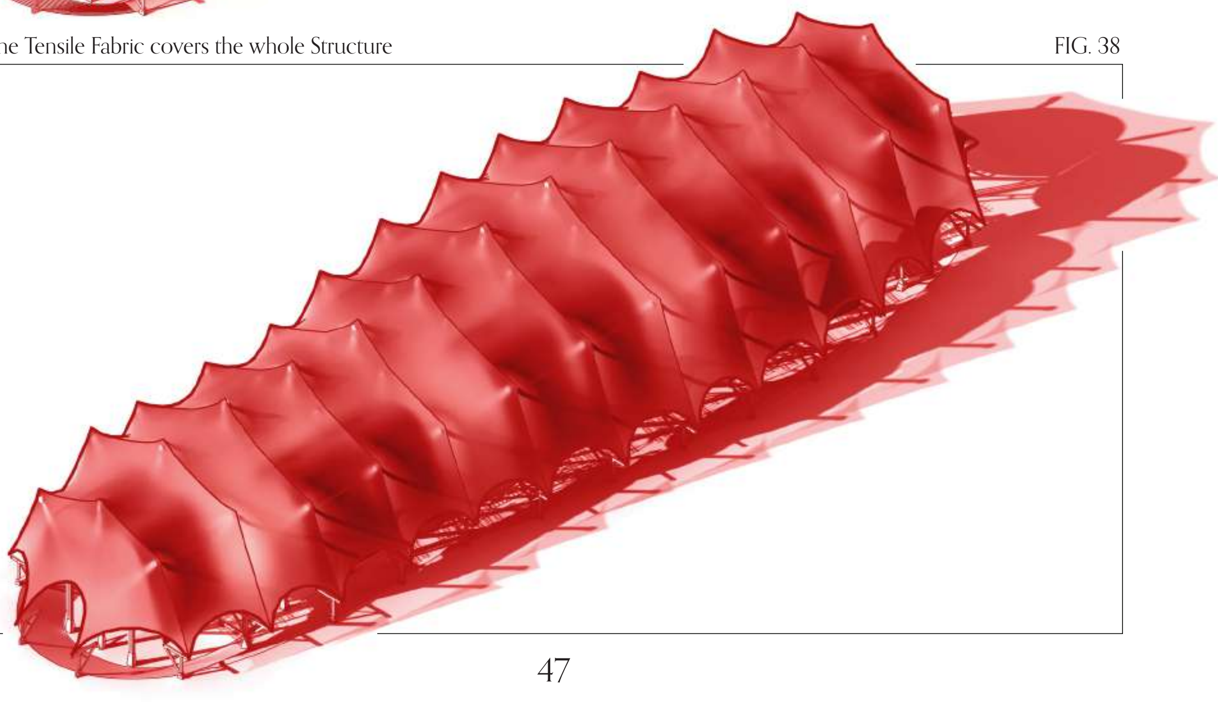
Modules placed along the Spine

FIG. 37



The Tensile Fabric covers the whole Structure

FIG. 38



The Spine

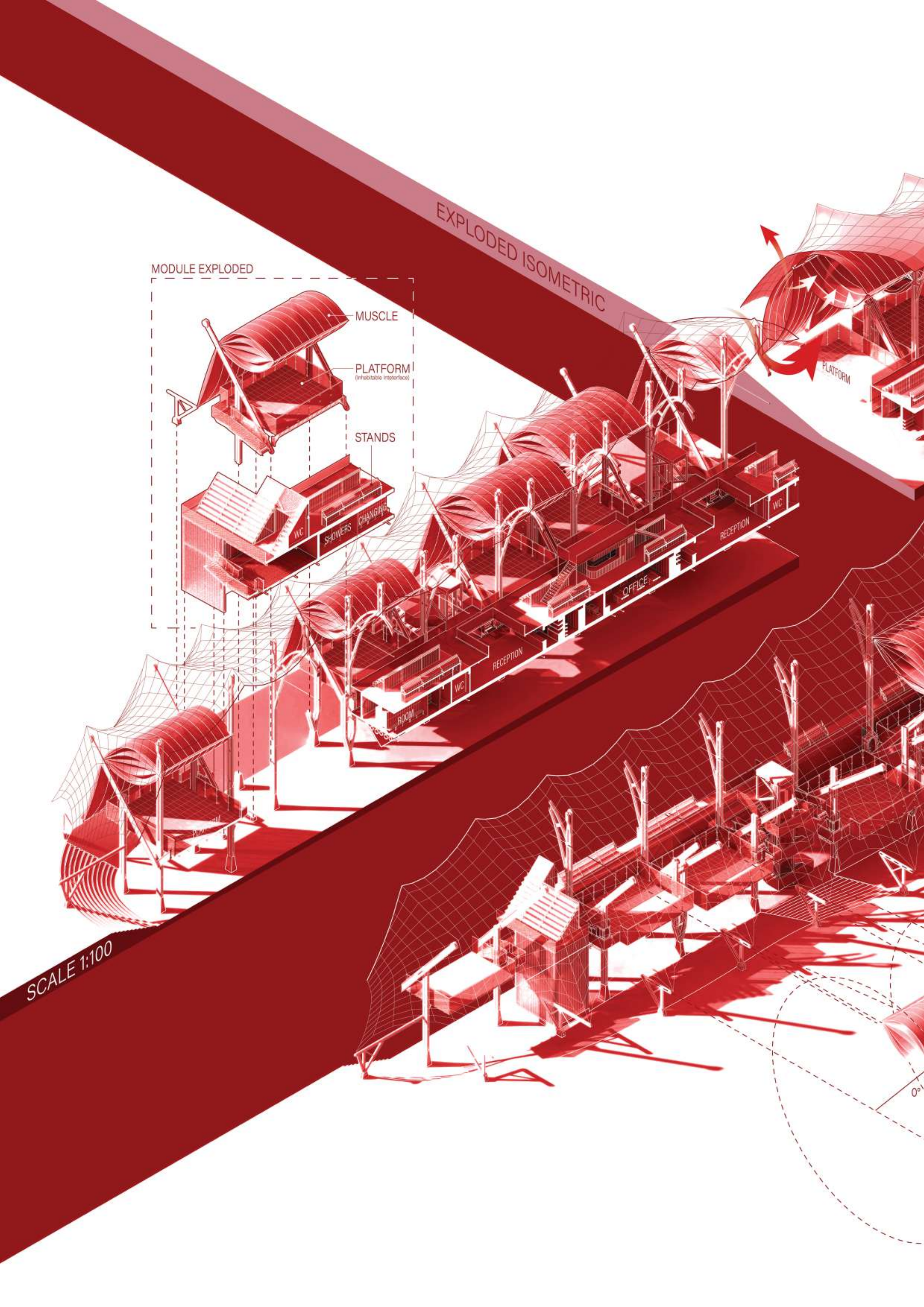
On each side of the spine there are changing rooms [FIG. 36, a_1, a_2] that appertain to seven of the platforms each. In between these chaning rooms there is an office space [FIG. 36, b] which is central and has close connection to everything. Most importantly it connects directly to the entrance areas which themselves connect to the vertical communications on each side of the structure. This area is reserved for access to bathrooms within the changing room volume as well as a reception desk on each end of the office volume. There is a specific rythm to the module placement which leaves space on each short end of the structure, that rhymes with the space for the vertical communication. These spaces are used for storage supporting the platforms.

The structure itself has gothic arches from which the muscle is adhered to [FIG. 37] as well as the fascia or the translucent fabric [FIG. 38].

The Fascia

The fascia has the important function of climate protection while enabling air to be let in and out to ventilate the building. Air is let in through the bottom and is eventually pumped out by the muscles. Another aspect of the building is displaying the pumping movement to create the building's pulse. Through the translucent fabric you can make out the shape of the muscles and their movement, movement which is translated to the geometry of the facade which is constantly morphing as the building is pulsating.

There were plans for the muscle to be poking through the building but in accordance with the interview with Malgorzata Zboinska the intent is not to provoke and poking holes in the fascia might evoke the appearance of wounds. Instead the decision was made to keep the outer layer intact and let the light come through as well as the muscle movement to create a dynamic facade.


EXPLODED ISOMETRIC
MODULE EXPLODED
MUSCLE
PLATFORM
(Inhabitable Inteterface)
STANDS
WC
SHOWERS
CHANGING
PLATFORM
RECEPTION
WC
OFFICE
RECEPTION
WC
ROOM
SCALE 1:100

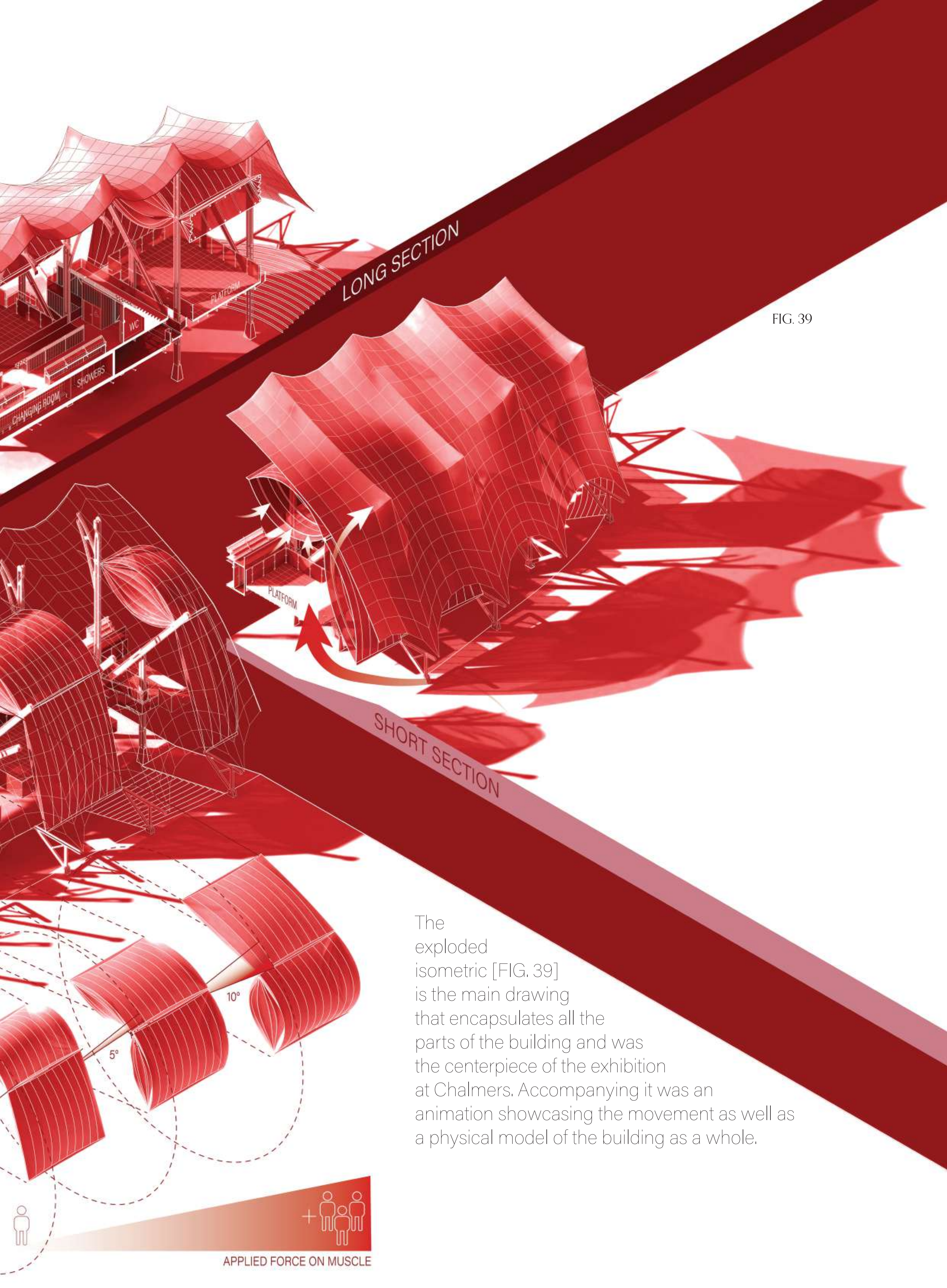


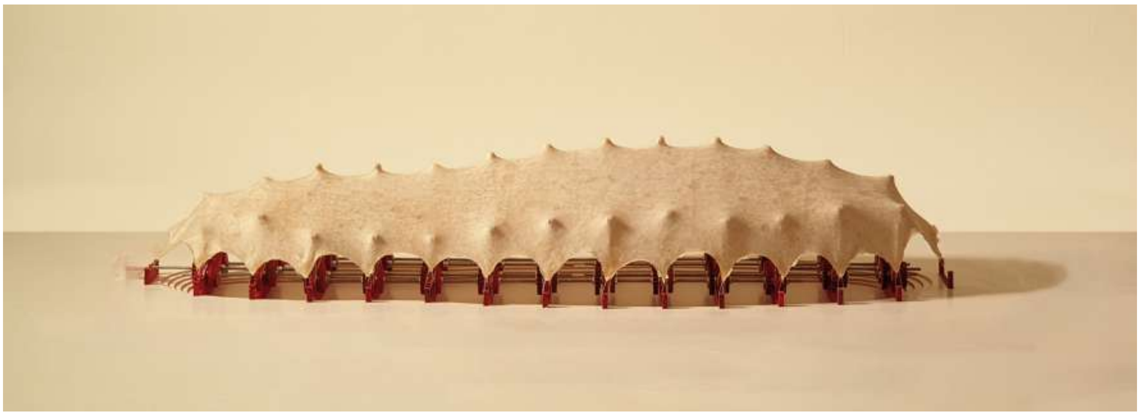
FIG. 39

The
exploded
isometric [FIG. 39]
is the main drawing
that encapsulates all the
parts of the building and was
the centerpiece of the exhibition
at Chalmers. Accompanying it was an
animation showcasing the movement as well as
a physical model of the building as a whole.

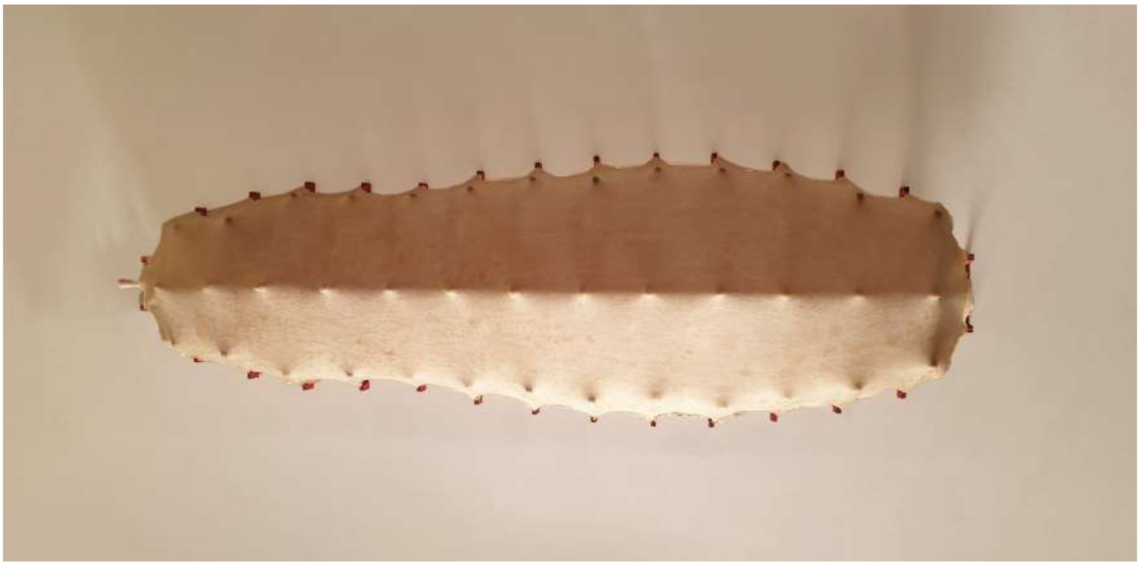
Front View of Physical Model with Latex

FIG. 40

Side View of Physical Model with Latex FIG. 41

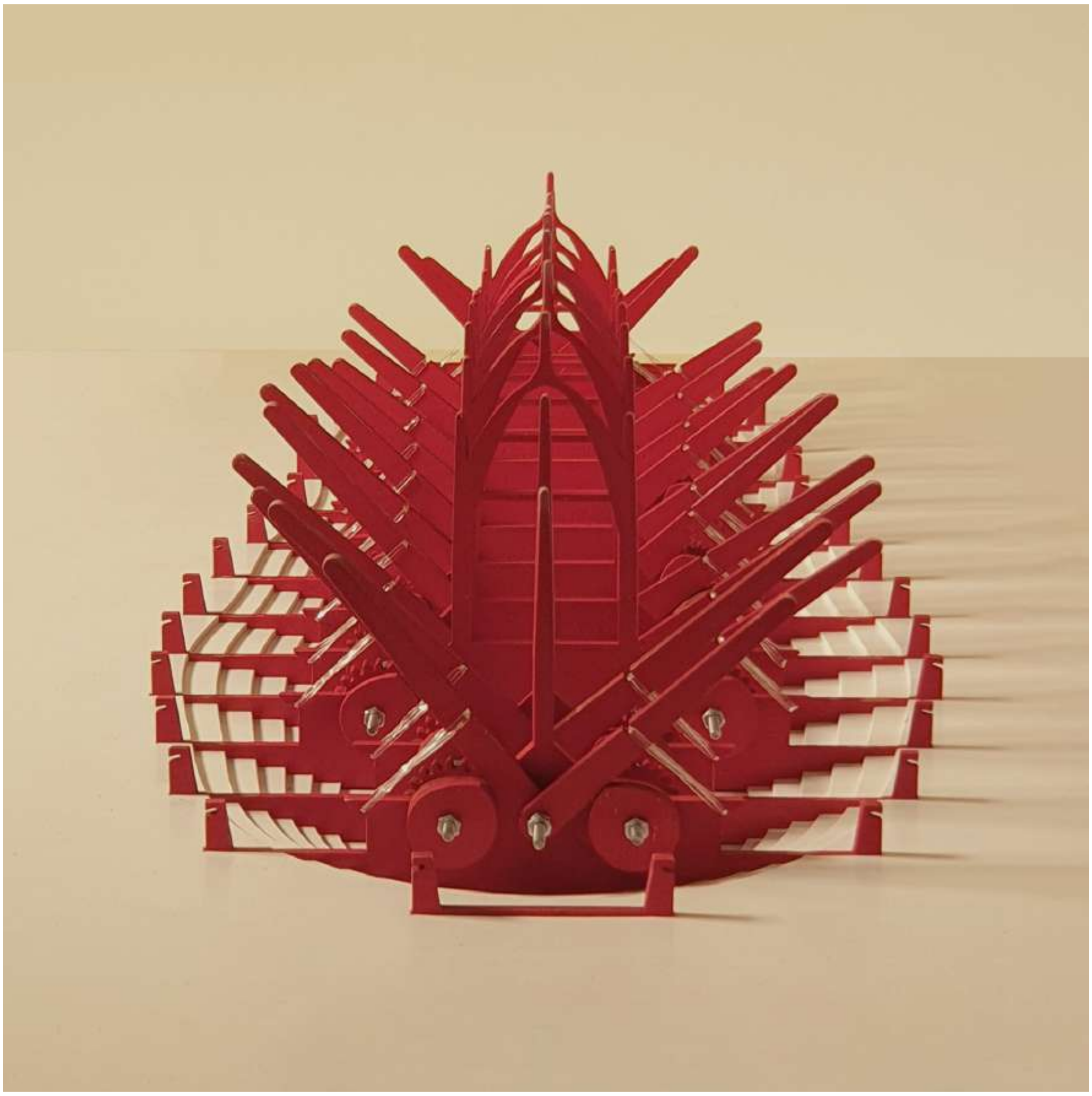


Top View of Physical Model with Latex FIG. 42



Front View of Physical Model without Latex

FIG. 43



Top View of Physical Model without Latex FIG. 44

Physical Model

The movement of the building is the most important aspect which implies that the physical scale model also needs to reflect that. To manage this the model is made out of several sections, each with arms controlled by wheels with varying radii. The arms are tensioned by rubber bands keeping them taut towards the wheel's edge. These wheels are all connected to the same axles which themselves are connected by cogs.

Just like the actual building these arms support an outer fabric that will be moving along with the arms. Unlike the actual building there are no muscles attached to the arms which means that having the fabric be semi-transparent is not necessary but might be beneficial to showcase the intricate mechanism

All of this was the intended way for it to work but in the end it was not able to be realised in this manner. The additive friction created throughout the model meant it became impossible for the lever to turn the axles without the cogs popping out of their positions. In the end the moving model became a stationary one that instead showcased the building at one moment in time with all the arms in a neutral position.

Results

The research has resulted in a proposed structure spanning 140 meters with a width of 45 meters inhabiting a Body Movement Centre housing 14 exercise halls of various sizes with stands for spectators as well as all essential supporting facilities such as storage, bathrooms, office and changing rooms. This makes it ideal for sporting events of different kinds as well as everyday use.

The overall appearance and aesthetics of the building is a mix of industrial and organic with a hard steel structure juxtaposed with the soft tensile covering. An outer fabric with transparency that hints at the inner workings of the building, displaying the pulse of people coming and going to the outside public walking by. At first glance the building may seem odd but not necessarily too different from other tensile structures. It is when observed over time the seemingly simple appearance starts to confound and engage the viewer.

It is not only for the visual spectacle that the building moves. It also serves the purpose of aiding in the natural ventilation which suits the building's function of providing adequate training facilities. While people are using the building they get a first hand response from their own actions that transmit through the building. This response is both haptic, visual and most likely auditory, activating several senses not normally engaged by a building ensuring that there is a mindfulness of what the building is providing. This mindfulness makes it clear that one's action is important for the building to aid in the comfort of the inhabitants, therefore a symbiotic relationship between body and building is established.

All of this relies on the muscle mechanism being functional which there is no certainty for provided in this thesis due to lack of expertise within fabrication of textiles in combination with time restraints. If the functionality is assumed then the thesis did result in the creation of a prototypical building that imbues the structure with movement and does not limit itself to a kinetic facade. It also makes full use of the material properties of the tensile fabric to have a semi-transparent hull that provides the layered luminosity that was aimed for to get both a sense of flesh but also a sense of life.

Discussion

With the building ideated there can now be an evaluation of how it stacked up to the aims of the thesis. Therefore, discussions will focus around the aims of the thesis which was;

> *Exploring the imbuing of kinetic elements into the load bearing structure of the building, facilitating the movement of the building.*
>
> *Form an empathetic relationship between body and building by using architectural muscle to create a conncetion.*
>
> *Use tensile fabric with translucency to imitate the qualities of neoplasm through layered luminosity and pulse, enhanching the feeling of a building that is alive.*

As for the kinetic elements they are well incorporated into the structure and placed where they can most easily perform their purpose of creating drafts for the ventilation of the building. Their placement also creates a gradient of movement where the edge of the building is loose while the core is rigid. This gradient allows for all the necessary functionalities to exist within the boundaries of the structure.

At the border the elements of the building come together nicely. The tensile fabric leaves openings for the draft to bring in fresh air when the existing stale air is inhaled by the muscles. Then it can be exhaled to the outside by the muscle. The necessary close proximity of the muscle to the platform is also preferable since that is where activity will happen which leads to more heat generating.

This fact leads to the second aim which was to create a more empathetic relationship between body and building which is what happens when the building responds to people's movement and reciprocate with the increased ventilation. This increased draft will be noticeable not only through the sight of the muscles moving but also by the sensation of wind against skin which gives a haptic response. In accordance with Pallasmaa's arguments in The Eyes of the Skin (2012) the haptic response makes for a more dynamic and layered experience. What is interesting is the concept that the haptic response is not necessarily a direct contact with a material but could also be provided at a distance. Since the function of the building is one that requires additional cooling this action bythe building is also appreciated by the inhabitants which is, of course, important. One might have had the experience of an electronically controlled shutter system that closes the shutters just as the sun shows up and provides well needed light.

Lastly, the appearance of the building is supposed to evoke a sense of an organic structure that has a pulse and is "alive". The layering of tensile fabric, arms, muscles and the core creates another kind of gradient of coverage that does provide the layered luminosity that is described by Cruz in the Kunsthaus Graz (2013). While Kunsthaus Graz has a digital display that handles the pulse this project creates it through mechanical movement only.

The mixing of industrial and organic expressions was an effect of the fear that creating an artificial organic structure would come off as disingenuous since there was no time to organically generate it. The result is an inversion of the cyborgian body that Cruz (2013) mentions in his book where the human body adopts technological advancements, instead this building adopts organic, in appearance, muscles. This juxtaposition was a welcome surprise and might put forward the idea that this building is simply a stepping stone in the direction of a fully organic building.

The ambition of the thesis was to manage all the intricacies of the project itself but both the lack of experience and time restraint meant the project fell short. The resulting structure should be thought of as a prototype to be improved upon and inspired by. It is merely a stepping stone towards the unreal living, breathing and pulsating architecture that now is a little more real.

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Architectural Muscle

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