ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

MATERIAL BASED COMPUTATION: COMPOSITES FOR A RESPONSIVE FAÇADE DESIGN

M.Sc. THESIS

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Department of Informatics

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

MALZEME TABANLI BİLGİSAYIM: ETKİLEŞİMLİ CEPHE TASARIMI İÇİN BİLEŞİK MALZEMELER

YÜKSEK LİSANS TEZİ

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Zeynep Sümbül Enhoş, a **M.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID **523111020**, successfully defended the **thesis** entitled "**MATERIAL BASED COMPUTATION: COMPOSITES FOR A RESPOSIVE FAÇADE DESIGN**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 11 April 2014
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To my family,

FOREWORD

I would like to dedicate this study to my family, Fatma ENHOŞ, Sabri ENHOŞ and Mustafa Kemal ENHOŞ who have been supporting me in every field of my life.

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Zeynep Sümbül ENHOŞ
Architect

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ABBREVIATIONS

Fig : Figure
CAD : Computer Aided Design
CAM : Computer Aided Manufacturing
CNC : Computer Numerical Control
FGM : Functionally Graded Materials
FU : Functional Units
TS : Technical Solution
GARM : General AEC Reference Model
AEC : Architecture Engineering Construction
Ghx : Rhinoceros 3D model program add-on Grasshopper file
PI : Performance Indicators
BIM : Building Information Modeling

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MATERIAL BASED COMPUTATION: COMPOSITES FOR A RESPONSIVE FAÇADE DESIGN

SUMMARY

Materials are at one of the main intersections between different disciplines, such as architecture, engineering, and chemistry. Collaboration among these disciplines allows the use of materials in architecture not as givens but as dynamic input, with their inherent behaviors. Collaborative work supports innovative and interactive design performance by taking advantage of the inherent behaviors of materials reacting to the changes in the environment. It is necessary especially in performance defining phase, to gain maximum performance and desired appearance at the same time without using any additional systems.

Basic 3D programs help designers to visualize the design and in some cases test the performances, however. They usually do not go beyond the borders to explore the emergence potential of inputs. The logic of the model is often limited with shapes and creates a visual relation with shapes via materials. This overlooks the potential of materials to rule their environment and create responsive, interactive designs, if they are used as performance-based elements. The performance based use of materials that allows for interactivity and reactions, helps to create flexible spaces without the dictation of a use for a specific aim.

Materials can be combined together to augment the influence of both homogeneous and continuous reactions to the environment. The reaction of a material to a condition creates a movement in the architectural component, however if environmental condition is continuous, this movement can turn into a motion that gives a performance based working discipline to the design.

This thesis has aimed to create a façade system with composites to start a discussion on the physical behaviors of materials, on digitally simulating these behaviors and creating digital emergences. A façade is a building component that is in a relation with both the inside and the outside. It should be designed as performance based besides being aesthetically valuable. A façade should have a relation with the other building elements, while being an interface between two environments. A façade is the most convenient element in a building to have motion and to be multifunctional, and to give shape to space as part of its performance.

Material computation is an ongoing and fast developing area of study in architecture. The notions of responsive, kinetic, and sustainable design in architectural applications require an increased use of computational tools. Material computation allows for iterations and variations by combining the physical and chemical specifications of materials. Those iterations may help natural materials and sustainable systems, to take the place of performative chemicals via providing the same properties with them. Exploring new combinations for performance through

both physical and computational experiments leads to a sustainable design without the use of any harmful chemicals and without unnecessary energy consumption.

In the thesis, bioplastics are used to create the combinations that create the façade system proposal. The criterion of the composite is for it to be consisting of multi-layers of the same material, which can be varied in density.

After a literature study of materials, façade systems, bio plastics and computation, observations are made while testing the physical capabilities of bioplastics. Bioplastics are biodegradable and sustainable materials, widely used in product design. Although the examples of their use in building elements are limited, there are a few examples such as.

Arboskin, created by a collaborative work of ITKE (Institut für Tragkonstruktionen und Konstruktives Entwerfen - Institute of Building Structures and Structural Design) students. However, these examples are assuring in the use of bioplastics in façade designs, they usually do not make use of the flexibility of the material. Bioplastics can be used as solid outputs and/or soft, flexible elements, they have the potential of being the load bearing system of its own while being a flexible component of the design. Using one material both as a structural system and the skin allows for extending the area of use according to desired performances.

In the physical experiments, bioplastic' possibilities and the potentials of probable composites are observed and a small database of material behaviors is noted. The database is created by collecting the results of physical experiments of bioplastics, which are aimed to test the material phases and densities of bioplastics.

After physical experiments, the acquired data on bioplastics is used for computation. Unlike basic 3D models, computation refers to an information-based model from which the data of the design can be extracted. In the scope of the study, four 3D computational models are generated to simulate the observed potential of both solid bioplastics and soft bioplastics. Models are generated by using the result data of physical experiments.

Computational tools have evolved and varied. They allow for digital testing and iterations of design under observed properties and behaviors of materials. Computation is used not only for the design phase but also to predict probable problems for the construction. The computational models that are created for this thesis test the pneumatic system of soft skin that are created by physical properties of soft bioplastics leaves, and the variable adaptation of the solid skin is tested. A surface is defined in Rhinoceros platform with Grasshopper and is inflated to gain pneumatic pillows that change the thickness of the material by inflating or deflating. The structure of the composite, the solid part, is accepted as the limit of the pneumatic system and protects the system to inflate more than it can. The Grasshopper definition is used to test the inflation level. The shape of the solid part directly affects the shape of the soft part. A few attractor points are generated in the model to serve as, the peak points of the pneumatic pillows that simulate the inflation and are limited by the solid body. A gradient tool is added to the system to see the limit of inflation.

The façade proposal creates a building element that interacts with the user and the environment that creates a motion according to external forces.

As the pneumatic pillow inflates the thickness of the soft skin decreases and the transmission level of a pillow increase in contrast to the thickness. The decrease in thickness allows for visual communication between two separated environments. On the contrary, as the pillow deflates, the thickness turns into its original value and the visual communication decreases.

The thesis aims to combine knowledge from different disciplines to achieve maximum performance and emerging "performative and interactive architecture" via gained performances. Multidisciplinary work on materials leads to an increase on performance of materials and composites. The increasing use of composites and the potentials of materials based on inherent behaviors trigger environmentally sensitive design developments. Materials withhold the potential for designers to achieve desired performances in building elements without any environmentally harmful solutions that only give the material stability and visual aesthetics that limit the responsiveness of the design at the same time. With cross-disciplinary knowledge that guides innovative combinations, choices, responsive composites can be generated, and multi-functional, reusable, dynamic spaces can be designed beyond selective exhibitions to widespread use in daily life. The approach in the thesis does not limit itself to its main domain, but utilizes knowledge from other domains.

MALZEME TABANLI BİLGİSAYIM: ETKİLEŞİMLİ CEPHE TASARIMI İÇİN BİLEŞİK MALZEMELER

ÖZET

Değişen ve gelişen dünyada, bilgi tabanlı düşünce sistemlerine ve basit orijinal temellere dayalı çözüm üretme giderek yaygınlaşmaktadır. Tasarım da bağlamından kopuk ve görsel yönü baskın bir ürün olmaktan çıkarılıp, neden oluştuğuna yoğunlaşarak geliştirilmelidir. Malzemenin tasarımın vücut bulmasına katkı sağlayan en önemli etmenlerden biri olması, tasarımın özelliklerinin belirlenmesinde ve kullanım amacında da büyük bir role sahip olmasını gerektirir.

Günümüzde yaygın tasarım bağlamından kopuk olarak sadece form görselleştirme üzerine yoğunlaşmış durumdadır. Düşüncenin vücut bulmasında kullanılan malzemeler, bir performans belirleyici olarak değil, belirlenmiş şekilleri niteleyici, görselleştirici olarak kullanılmaktadır. Bu durum üç boyutlu dijital modellerin mantığı ile açıklanabilir. Mimari görselleştirme alanında, öncelikle form belirlenir ve malzemeler o formların uyum içinde görünmesi için *map* olarak şeklin üzerine atanır. Malzemeler ile ilgili bu tarz kullanım durumları sadece mimari görselleştirmelerde değil, tasarım sürecinde de gözlemlenmektedir. Malzemelerin kalıtsal özellikleri ve sahip oldukları etki-tepki imkanları vardır, fakat bu durum genellikle malzeme için bir dezavantaj olarak betimlenmektedir.

Tasarım, sadece bir görselleştirme değil, kullanıcı ile obje, mekan arasındaki ilişkiyi çözümleme ve bu ikililer arasında bağlantı kurma çalışmalarının bütünüdür. Bu bağlantı aşamasında mimarlar, mühendisler, araştırmacıların birlikte bir karar mekanizması oluşturması ve multi-disipliner bir düşünce sistemi ile sonuca ulaşması gerekmektedir.

Malzemeler bir araç olmaktan çıkıp, performans belirleyici olarak kullanılmaya başlandığından beri, malzeme potansiyelleri ile ilgili araştırmalar, çalışmalar yapılmıştır. Gaudi, Fuller, Prouvé ve Otto gibi deneysel tasarım yaklaşımcıları gerek mühendislik gerekse görsellik alanında malzemeler ve potansiyellerini incelemiş ve performans belirleyici etkenler arasında malzemelerin de olduğu örnekler ortaya koymuşlardır. Örnek olarak Antoni Gaudi, mimari çalışmalarını öncelikle 1/1 ya da 1/20 gibi ölçeklerde ve orijinal malzemelerle fiziksel model yaparak test etmiş ve malzemelerin dayanımlarına göre taşıyıcılık gibi problemleri, içinde bulunduğu döneme göre sıra dışı bir şekilde çözümlemiştir.

Malzemelerin davranışlarının olmasının dezavantaj olduğu bir dünyadan bu potansiyelin avantaja dönüştürüldüğü bir dünyaya yönelim, hem tasarım hem de mühendislik alanlarında ilerlemeye yol açmaktadır. Hesaplanabilir malzemeler ve hesaplamalı tasarım süre gelen bir çalışmadır ve uzun yıllardır üzerine farklı araştırmalar, projeler yapılmıştır. Fakat teknolojinin gelişim ivmesinin artmasıyla hesaplamalı tasarımlar gelişmiş ve yapım öncesi süreçte performans ve çalışma ilkelerine ışık tutmuştur.

Kullanıcı etkileşimli tasarımlar, günümüzde yaygın olarak kullanıldığı gibi, sadece bilgisayar sistemleri ile değil, malzeme davranışları ile de elde edilebilir. Dinamik, kullanıcı ve çevresel etkenlere göre form değiştiren, farklı kullanım potansiyelleri sunan tasarımlar, geleneksel çizgiden birçok anlamda uzaklaşmayan tasarım dünyasına yeni yönler çizebilir.

Yapılı çevrede bir inceleme yapıldığında kullanıcı ve çevre ile direkt ilişkili olan en büyük yapı elemanı olarak cepheleri görürüz. Cephe sadece bir kabuk değil, aynı zamanda bina performansını büyük oranda belirleyen, iç ortam ile dış ortam arasında bir dengeleyici olan, tüm bina sistemleri ile doğrudan ilişkili olan ve bütün bunların yanında estetik kaygıları da olan bir yapı elemanıdır. Kullanıcı ve çevre ile doğrudan ilişki içinde olması nedeniyle, bu tez kapsamında malzeme potansiyelleri bir cephe önerisi geliştirilerek tarafımdan incelenmiştir.

Sürdürülebilirlik, kaynakların dengeli kullanımı ve doğal yaşamın sağlıklı devamını sağlamak için, hızlı tüketim ve değişimler yaşadığımız bu dönemde öncelikli ve büyük önem arz etmektedir. Bu nedenle kullanılan malzemelerin doğal kaynaklı olup olmamaları ve çevreye verdikleri zarar ya da çevreye olan katkıları, tasarım kimliğinde önemli etkenlerden biri olmalıdır. Birçok malzeme, etki alanının ve özelliklerinin arttırılması, aynı zamanda da içsel davranışlarının, tepki mekanizmasının nötrlenmesi için farklı katkı maddeleri ile birleştirilmekte ve doğallıktan, yeniden kullanılabilme özelliklerinden mahrum bırakılmaktadır. Fakat malzemeler, özelliklerinin geliştirilebilmesi için doğal yollarla birbirleri ile bağlanabilir ve bileşik (kompozit) malzemeler oluşturulabilir. Arttırılmış etki alanı ve özellikler, günümüz tasarım ve uygulama alanlarında öncelik kazanmışlardır. Fakat kompozitler sadece farklı malzemelerin birbirine entegrasyonu ile mi oluşturulur? Yoksa aynı malzemenin farklı özelliklerdeki türlerini bir araya getirerek de kompozit malzemeler ve arttırılmış performanslar elde edilebilir mi?

Tez kapsamında, gerek aynı başlık altında olduğu malzemelerin doğaya zararlarının aksine tamamen geri dönüştürülebilir olması, gerekse araştırmaları süregelen ve gelişen bir malzeme olması nedeniyle biyoplastikler incelenmiştir.

Biyoplastikler tamamen doğal malzemelerin birleşimi sonucu elde edilen, katkısız olanlarının %100 geri dönüştürülebilir olduğu bir sınıftır. Ayrıca içeriğine eklenen malzemelerin oranlarının değiştirilmesi ile farklı fazları ve potansiyelleri ortaya çıkmaktadır. Gliserin, nişasta, sirke ve su kullanılarak evde basit örneklerinin üretilebileceği bu malzeme oranlara göre yumuşak, sert, geçirgen, yarı geçirgen gibi özelliklere sahip olabilmekte, sertlik derecesine göre hem taşıyıcılık özelliği kazanmakta hem de şekil değiştirme potansiyeline sahip yumuşak bir ürün olabilmektedir.

Malzeme özelliklerinin hesaplanabilir ortamlarda devam ettirilmesini ve yeni çeşitlemelerinin oluşturulmasını, aynı zamanda içsel özellikler ve etki-tepki mekanizmasının kullanılmasıyla kullanıcı etkileşimli mekanlar kurgulanmasını öngören bu tez kapsamında öncelikle biyoplastikler ile ilgili literatür araştırması yapılmış ve bugüne kadar üretilen örnekler incelenmiştir. Kullanım alanının son dönemlerde arttığı bu malzemenin, dünya genelinde sayıca çok az bir oranda yapı elemanı olarak kullanıldığı gözlemlenmiştir. Fakat son yıllarda çeşitli oranlar denenerek malzeme ömrü ve statik yapısı iyileştirilmiş ve farklı yapı ölçeklerinde, pavilyonlarda kullanılmaya başlanmıştır. ITKE (Institut für Tragkonstruktionen und Konstruktives Entwerfen) tarafından yapılan Arboskin, biyoplastiklerle üretilmiş bir cephe tasarımıdır.

Fiziksel deneylerde malzeme, farklı oranlar denenerek ve ek katkı maddeleri ile birleştirilerek denenmiştir. Sabun, toz jelatin gibi katkılarla istenilen performanslara ulaşım sağlanmıştır. Bir biyoplastik karışımına eklenen toz jelatin, malzemenin dayanımını oldukça arttırmakta ve zar kalınlığında da kullanım alanları oluşturmaktadır. Sabun vb. eklentiler ise köpürme sonucu malzemenin belli alanlarında boşluklu bir yapı oluşturulmasına ve performansının arttırılmasına yardımcı olmuştur.

Fiziksel deneylerin ve malzemenin temel etki alanı ve limitlerinin belirlenmesinin ardından, varyasyonların üretilmesi ve potansiyellerin ölçülmesi için, hesaplanabilir ortamda çalışmalar yapılmıştır. Hesaplanabilir modeller, basit üç boyutlu modellerin aksine, bilgi içerikli ve sebep sonuç ilişkisi altında kurgulanmış bir çeşit simülasyonlardır. Teknolojinin gelişimiyle yaygınlaşan bu programlar, yapım aşamasından önce hem bütün detayları görebilmemize hem de olası tehlikeleri önceden sezebilmemize de yardımcı olmaktadır.

Rhinoceros 3 Boyutlu modelleme programı ve Grasshopper eklentisi kullanılarak oluşturulan biyoplastik cephe önerisinde 2 farklı modelleme yapılmıştır;

1- Esnek ve uyarlanabilen, yumuşak malzeme modeli.

2- Dayanımı yüksek, taşıyıcı özellikli malzeme modeli.

Bu iki farklı sınıfın birlikte çalışması ve bir yapı elemanı kompoziti oluşturması için farklı varyasyonlar denenmiştir.

Biyoplastiklerin istenildiğinde edinilebilen esnek yapısı, cephe sisteminin devinimini oluşturan sistem olarak kurgulanmıştır. Grasshopper kodu kullanılarak yapılan tasarımda çeşitli etki noktaları belirlenmiş ve malzemenin bu noktalardan şişkinleştiği modellenmiş ve tehlike sınırları gözlemlenmiştir. Taşıyıcı olarak kullanılabilen, yüksek fiziksel dayanımlı malzeme modelinde ise, dış ortamdan alınan farklı etkilere göre pozisyon değiştirme ve buna adaptasyon yeteneği sorgulanmıştır.

Cephe tasarımının genel yaklaşımında ise günün farklı zamanlarında dış etkenlere, kullanıcı, hava sıcaklığı gibi etkileyicilere göre pnömatik bir sistem oluşturan, şiştikçe saydamlığı arttırıp görsel ilişkiyi arttıran ve ışık geçişini sağlayan, havası indikçe de opaklığı artan ve hem görsel ilişkiyi hem de geçiş oranını azaltan bir cephe kurgulanmıştır.

Malzemeler, sadece görsel bir obje olmanın çok ötesinde, yakın çevresine kendi kurallarını gösterebilecek ve buna göre etkileşime girerek yeni formlar oluşturabilecek potansiyele sahiptir. Bu nedenle malzeme kullanımları ve araştırmaları, disiplinlerarası ortamlarda ve performans tabalı olarak yapılmalıdır. Tez kapsamında yapılan çalışmanın gelecek senaryolarında, bu işleyiş yönteminin farklı malzemeler ve kombinasyonlarla da denenmesi ve oluşturulan bileşiklerin çeşitliliğinin arttırılması hedeflenmiştir. Hesaplanabilir ortama aktarılma aşaması öncesinde yapılan fiziksel deneylerin rastlantısal ilerleme potansiyeli ve form oluşturma özellikleri incelenmeli ve bu rastlantısallığı dijital ortamda da belirlenen parametreler altında kurgulanabilmesi sağlanmalıdır.

Tez, malzeme potansiyellerinin etkin ve doğru kullanımı sonucunda, sürdürülebilirliğin artması, kullanıcı etkileşimli, form değiştiren, tepki veren tasarımların vücut bulması ve tüm bu gerçekliğin bilgisayar ortamında da sunulabilmesi için bir ön çalışma olarak öngörülmüştür.

1. INTRODUCTION

As natural and artificial environments change due to technological developments and needs, there is a return to the origins in managing knowledge based thinking and the interest in attempts to find solutions in the basics in many areas. In the area of architecture and construction, abstract and intuitive thinking is generally separated from construction knowledge and practice. However in collaborative work, understanding materials not as givens but as dynamic design input with their inherent behaviors and capabilities holds great potential for innovative designs.

Materials offer use in functional, spatial performance and as form generators. Their coded inherent features can be ruled in design through parameters. Material behaviors as action and reaction to changing conditions allow for more flexible, user interactive and responsive places. Even if synthetic materials have harmful and irreversible effects on the environment, a full understanding and careful use of chemical properties is open to development in application fields such as architecture.

Architecture is a dynamic and fluctuant discipline, which renews itself according to the current conditions of the environment and the social structure. Hence, its relationship with other disciplines and the environment is strong. Because of the architects' role in the formation of the environment, there is a responsibility for balancing the constructed environment and natural environment.

Material computation is an ongoing and fast developing area of study in architecture. The notions of responsive, kinetic, sustainable design in architectural applications require an increased use of computational tools. Material computation allows achieving iterations, variations by combining the physical and chemical specifications of materials. Those iterations may help natural materials and sustainable systems, to take the place of performative chemicals via providing the same properties with them. Exploring new performance combinations, generated by both physical and computational experiments, leads to evolve into a sustainable design without using any harmful chemicals and without unnecessary energy consumption.

1.1 Purpose of Thesis

This thesis is on the issues of materialization, functions, and potentials of materials, computational materials, and computing the real behaviors of materials. These issues will be examined through the design of a façade system. A material example, namely bio plastics, is going to be used to test the probability of creating new performances of materials, by defining their cellular, biological or physical specifications, and the probability of creating new potentials of materials from their behaviors by studying the system from the building element to the whole. Inherent properties of materials will be tested to observe material behaviors that support flexible spaces and emergent form generation via computational tools.

The thesis aims to combine knowledge from different disciplines to get maximum performance and to feed emerging "performative and interactive architecture" via gained performances. Multidisciplinary work on materials leads to an increase on performance of materials and composites. A façade as one of the most significant building elements with both aesthetic and performance concern, is going to be re-designed to reveal the potential of materials, composites and sustainable physical systems. A façade should be in a relation with both the interior and the outside while having physical relation with the structural and mechanical systems. Façades are the faces of the buildings; they have aesthetic aspects as well. Before discussing how to develop an interactive façade with focus on material research, first investigations are made into different façade systems. Understanding the objectives behind different designs of façades for different purposes, has helped in framing the current approach in the thesis. To improve the observation and shift the frame, material behaviors are observed by experiments under defined parameters.

To reach the interactive form, environmental conditions, different materials, and/or different densities of same material will be combined by both physical and computational experiments. The increased performance of materials and designed composites allows exploring changing, function based and emerging forms, sustainable emergent aesthetics.

1.2 Literature Review

Material computation is a growing field of research in architecture. Earlier examples shed light on the origins: experimentation with material morphologies.

Designers such as Gaudi, Fuller, Prouvé, and Otto were experimentalists. Their research was based on materials and focused on morphologies (Drew, 1976). They defined design parameters and tried to test the material by making one to one scale physical models. In their works, materials are not only visually expressed but also perform structural strength.

Research on materials evolved and combined with advanced technologies such as computation. Research and developing phase, which starts with physical possibilities and physical experiments are continued by computation to get variables, iterations. As the computational tools evolve, the shift in design and variations can easily observed from constructed environment.

Façade as one of the most interactive building elements is chosen as the object of the exploratory design in this study. Façades are not only skins or a transmission layers between two environments, but also systems that complements building organisation. The first housing is consisting of four walls, creating a rectangle that covers the human body. Those walls were the façade, the surfaces facing with the environment and a cover, protector for the human body. "Façade is positioned alongside other terminology such as envelope and skin... (Moloney, 2011)." As Moloney stated, façades are classified as an envelope or a skin for the interior. Out of being protective, façades evolved to provide many specifications such as being an insulation layer, protecting the privacy, allowing a limited transmission between two environments, providing an aesthetical appearance etc.

The choice of material that will be the other object of the design exploration in this thesis is based on the criteria that it should be flexible and form changing. Results of the research of materials reveal that the most flexible and elastic performance results, forms are gained from polymers such as membrane, plastics. After a research on solid polymers, (Vaz, M., Jr., et al., 2011) which suit the purpose, biodegradable polymers, which are also known as bio plastics, are chosen for the experimentation towards creating emergent forms and new potentials.

Recent publications about materials such as “Ultra Materials: How Material Innovation is Changing th World” (Beylerian, 2007), "On Growth and Form" (Thompson, 1942), "Performative Architecture Beyond Instrumentality" (Kolarevic et al., 2005), "Versatility and Vicissitude Performance in Morpho-Ecological Design" (Menges et al., 2008), "Digital Material Skins: For Reversable Reusable Pressel Vessels" (Hovsepian, 2012), "Designing Kinetics for Architectural Façades State Change" (Moloney, 2011), articles belongs to Neri Oxman, "Structuring Materiality: Design Fabrication of Heterogeneous Materials" (AD, p:78-85, 2010) delineate the current situation of material computation and responsive, interactive façade systems.Besides books, articles and magazines internet research takes a huge place in this thesis. Thus, material computation and digital form generations are ongoing issues websites belongs to universities, study groups, and workshop groups are one of the main reference for the thesis.

The thesis presents contraction and creep tests to physically observe material related form generations. Combination of different phases of one material is also observed both physically and digitally to apply on a façade.

1.3 Hypothesis

The thesis proposes an idea for an interactive and sustainable façade, by focusing on the inherent behaviors and specifications of material. The emergent design which changes in form according to environment and/or user induced changes. By physical and digital experiments generating a composite, which is the combination of a material with different densities, is aimed.

Computational modeling is a tool that is becoming a widespread approach to a multidisciplinary, mathematical and parametric designing. Unlike 3D modeling, computational modeling includes information of the inputs. Computational modeling helps to create variations of design with defined parameters. A model, in which levels of expansion are defined, iterations can be generated only between two terminal points of expansion levels. Hence, computational modeling helps to define a limited space, in which material properties allow the material to move and respond.

The façade that is going to be the case that is undertaken in this thesis aims to provide desired performances such as being responsive, being an equalizer between two different environments and being in a physical relation with other building elements. Basic properties of any façade such as being a shell and a controlled transmission of light and air are also considered as desired performances. The overall performance of the façade is to be achieved through an understanding and application of the behavior of materials in use.

In this thesis, the desired behaviors of the designed façade are directly related to the behaviors of bio plastics, which are the chosen materials. Some of these desired behaviors within the scope of the study are the capacity to expand, controlling the amount of light transmission, changing the view according to conditions. The argument of the thesis is to gather different information about materials and create a façade proposal based on inherent behaviors of materials, by using both physical and digital experiences.

2. MATERIAL AND FORM

"Existence is the extent of matter in space."

Descartes

Every organism has a nucleon, which has the code of color, shape, and orientation of the whole. Nature serves infinite possibilities to the Earth with those nucleons. Conducts, codes, inherent behaviors of the small "point" of the whole, defines the character. Materials, although they are not alive, have a system of which smallest part has the same behaviors with the whole.

The state of the material in design and construction is limited with static proofs. Material choosing phase is generally shaped around the appearance and one performance that is desired and required. Although materials are versatile and have different aspects and many capabilities, the material choosing part limits them into one specific characteristic feature. Rise of the industrial technology, caused the practice of architecture to focus more on form and weakened its relation with matter.

Applying the material to a pre-defined form is similar to basic 3D modeling. In 3D computational mediums, modeling programs, a surface or a volume is created and materials are defined for every element, performance. Then the material becomes a simple element to reach a specific result, instead of being a part of identity. Material is generally treated as a solution instead of potential. Design process can be formed according to the material properties. Materials have complex codes, potentials inside. The information that material has, should be used as a design parameter not only for the good-looking buildings.

Figure 2.1 and figure 2.2, which are outputs of the workshop "CAAD-High resolution", are images that show the unseen density of information. Materials have a code, which defines their characteristic specifications, and just like human genetics, materials have complex genetic schemas too. The complexity of the inner life of material leads it to higher versatility. This image of a digital model shows the inner potential of material by visualising the complexity that material has inside.

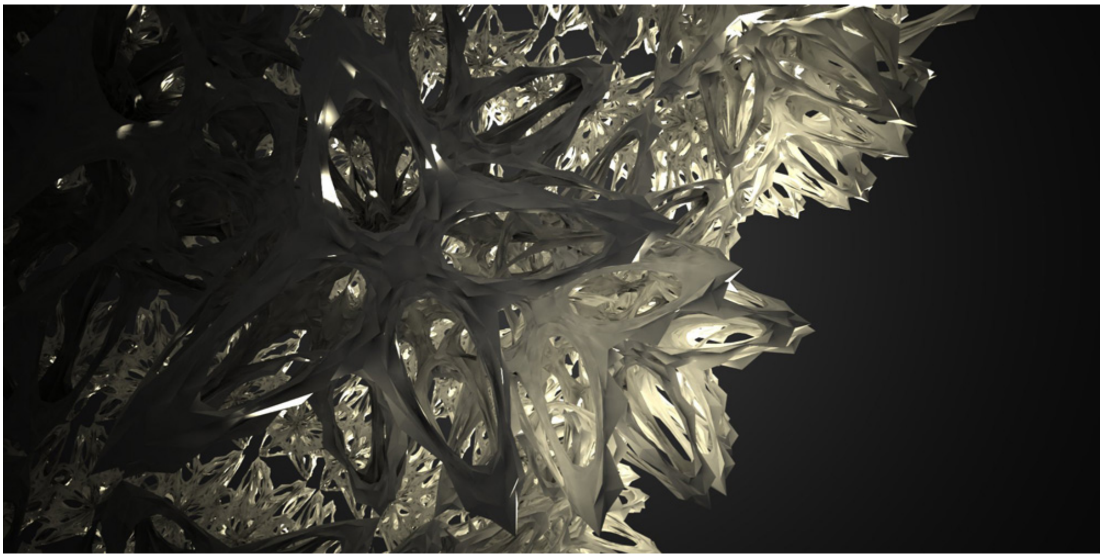

Figure 2.1 : Image that shows the visualisation of density of information of a material.[1]

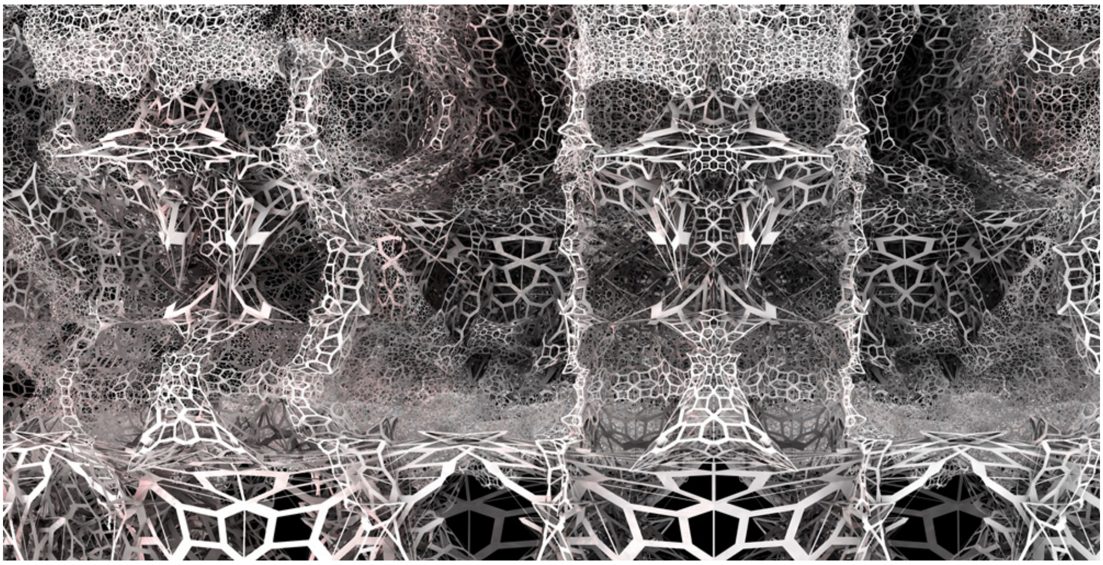

Figure 2.2 : Image that shows visualisation of density of information of materials-2.[2]

Information loaded in the molecules of material allows gravitating towards multiple directions. The images, shown above, reveal the computational model visualisation of inner organisation and information density of a material. The complex organisation and information that a material has is designed and visualised by

[1] Url-1: http://www.caad.arch.ethz.ch/blog/high-resolution/ , date retrieved 05.04.2014
[2] Url-1: http://www.caad.arch.ethz.ch/blog/high-resolution/, date retrieved 05.04.2014

students of ETH Zurich. Benjamin Dillenburger, Michel Hansmeyer and Hua Hao supervise the course "CAAD Theory". The complexity of materials has been a way to develop a computer-based approach to design strongly articulated spaces. Images reveal both systematic and complex sides of information density of a material.

Form follows function and function follows form are two different architectural approaches. The essential issue in the design process is the user according to the author. Therefore, everything should have an aim and should be designed according to the user. Dynamism emerges according to the users, the way of using. Every user can have a different style of using the space, the object, etc. and every time materials, composites can react according to the action. The size of the reaction also depends on the size of action and the inner organisation, information of the material as it shown before. Building elements, materials can have different actions to different users too.

Kloft (2005) asks, "What is 'free' in a free form?" and states that "If one compares the biomorphic structures found in nature with the material realities of tectonic languages in building, an obvious difference is that there are no straight lines and rectangular geometries in nature" (p.137). As designers, we are generally using rectangular shaped geometries to get the highest performance of both function and space. While thinking about the existence of materials, natural materials, designers first shaping the materials into a rectangular form, than apply the output to design. Then again, material in conventional design is merely a simple element, performing the suited performance. It is possible to use the material as a performance instead of as a physical input. Neri Oxman, in an interview, explains this issue in her project as:

> When you construct a building today, the pouring of the concrete is the same, whether it is a window, a wall, a ceiling or a support beam, regardless of the loads that are meant to be supported. My study suggests possibilities for pouring concrete in an innovative way that conserves materials. Naturally, this has design significance as well: We are creating a new language that is directly influenced by the behavior of nature. (2011)

In another interview about "The Science of Material Ecology" Oxman (2010) states that “Materials are indeed the new software. In the future, designers will be manipulating material behavior through fabrication just as they can control the shape of things through CAD. Eventually, materials will self-assemble to generate form”. As it is stated by Oxman, materials have the power to shape the form, with the development of CAD Technologies. The behaviors can be observed and iterations, variations can be generated according to physical experiments.

With flexible, interactive, dynamic design, form can follow function and function can follows form. A form that is composed of dynamic design can also bring the desired functions. Form in a static design limits the variation of usage and dictates the aim. However, dynamic designs both provide variation of usage and variation of form. Material and form can feed themselves. Materials create the building elements, details and building elements creates the form. As the details evolve and develop, the form and performance evolve as well. To sum up, by applying the material to a specific form without giving a chance to change the form, limits the potentials of material. Material and form can evolve together by thinking about the desired performance and potentials of inputs.

2.1 Forming of the Material

Materials that are being widely used in the area of architectural construction are generally designed and desired with minimum form change. Form changing and responsiveness leads to variations in use. To create a static and stable volume and design, less responsive materials are chosen or the response levels of materials are trying to be controlled and subsumed.

Attempts at reaching new, dynamic and interacted spaces direct researchers to experimentation, and heuristic studies of materials. Figure 2.3 shows a 3D printed house that is composed of only one material that is bio-plastics[3]. The model is created by using fibers of 3D printable material. As fibers come together, the form emerges and a living space is created. Single material is shaped by a 3D printer to create the space and the form, which is based on thin fibers. The application method and using of material is a way to a shift in design. The shift in design refers to changing and renovations on design method such as spectrum of area of use, application methods, and convenient conditions that affect design.

[3] Bio plastic: Bio based plastics. Differs from petroleum based and non-biodegradable plastics by being biodegradable, sustainable and biocompatible. "Bio based plastics or simply bio plastics made from renewable resources can be naturally recycled by biological processes, thus conserving limited natural resources (fossil fuels) and reducing greenhouse gas emission (CO2 neutral)" (Pilla S., 2011)

Figure 2.3 : 3D printed house, Protohouse, composed of a single material shaped in 3D printer.[4]

A team of architects and designers, including Gilles Retsin, Nicholette Chan, Aaron Silver and Sophia Tang, created the model and design of the Protohouse. The first prototype of 3D printed Protohouse is completed on 13th of February 2013. The design group explains their study:

> The model consists of 30 detailed fibrous pieces, which can be assembled into one continuous cantilevering structure, without need for any adhesive material. The arrangement of 0.7mm radius fibers displays a range of flexible textures and the ability to produce in-built architectural elements, such as structure, furniture, stairs and façade all in one instance. (2013)

The whole product is made of one material mixture, and pouring it as fibers give strength to the design. The design itself is also the load bearing system. The form is a

[4] Url - 2: http://www.3ders.org/articles/20130213-protohouse-2-first-3d-printed-home-can-be-assembled-within-a-day.html, date retrieved 06.04.2014.

non Euclidean Geometry designed according to user movements. The significance is that a single material solves all the problems and creates a habitat to a specific user. Is it possible to design an interactive habitat with this technique? The focus of this thesis is application method and material, the design can be created as interactive by augmenting the influence area of material, or material mixtures. Kloft (2005) explains the deviant architecture under the frame of structural design as "Non-standard structural design for non standard architecture". Solving the load, bearing system and making the design structure itself shifts the forms in architectural design and this is possible with material performances.

Materials can procure movements and responses from reactions that occur to an action. Learning of materials leads the design to be interactive with environmental conditions.

2.1.1 Learning materials

Even if they seem static in the constructed environment, materials can be turned into dynamic building elements. Inherent behaviors and acquisitions of materials directs the design to be interactive between the limits that is defined by the designer.

The project "Hygroscope" (figure 2.4) by Achim Menges is one of the examples on inherent behaviors of materials. In the project, Menges constructs a climate responsive architectural morphology by using the inherent behaviors of wood (Menges, A., 2012). The behaviors of wood under humidity makes this project dynamic, wood slices changes their expansion percentage according to the changes of environmental humidity. As the humidity decreases, the water in wood cells evaporates and changes their physical positions. Not only the physical form changing of the wood, but also the combination and construction take important place for this project. The idea can be applied to a façade system, where the humidity level changes a lot, and there is a need to balance it in the interior.

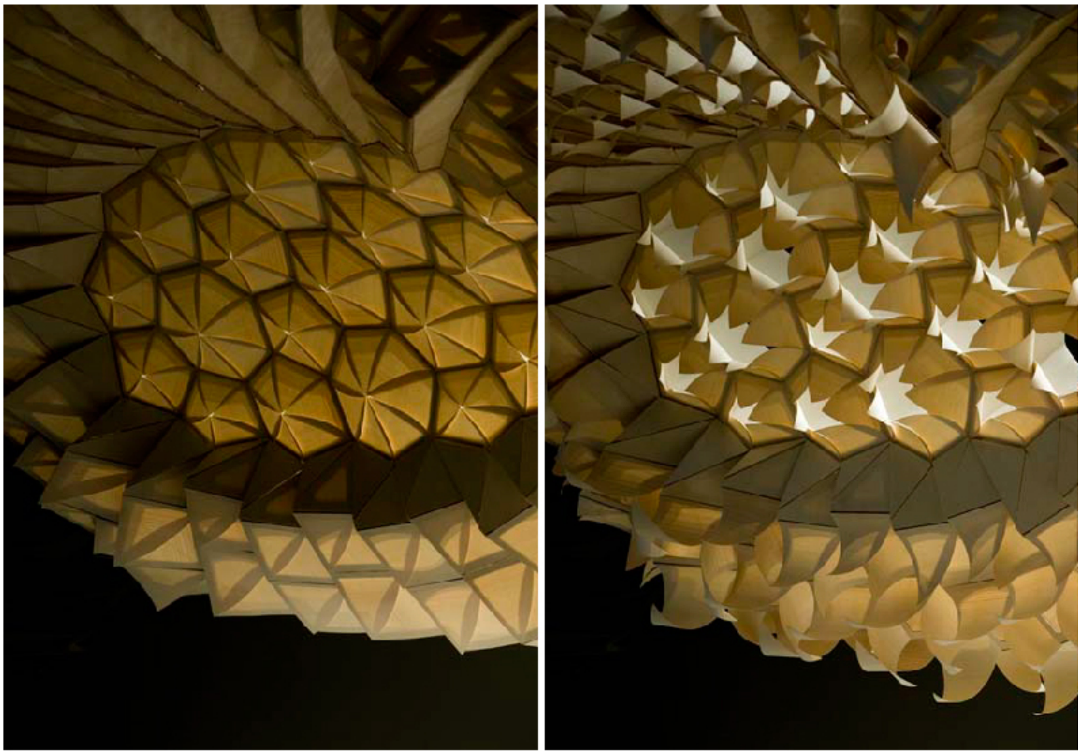

Figure 2.4 : Hygroscope by Achim Menges.[5]

Many architects and scientists are working on "breathable" and responsive façades. Making the material "alive", dynamics is the main concern.

In her project, "Metal That Breathes" architect Doris Kim Sung is using metals and by using different expansion levels of different metals, She achieves a dynamic system. When two thin metal leaves with different expansion levels are combined and heated, the system starts to bend. A "Breathing Façade" is designed and produced without building any automation system, but by using the potentials, inherent behaviors of metal leaves.

Based on inherent behaviors, materials can learn other behaviors. By forcing them to take a shape while using their inherent behaviors, designers can lead the material to react the same way after learning. Limitations of response can be obtained by directing the behaviors on defined ways. Once the material learns a reaction, it continues to react in same way for every time the action repeats.

Learning for materials is similar with human skin. When a person put on weights, the skin enlarges but because of being the first time of enlargement, the process causes

[5] Url 3 - http://www.achimmenges.net/?p=5083, 06.04.2014.

some difficulties, which resulted with chap. After turning back to initial weight and after required time, skin turns into initial form. For the second weight gaining, the enlargement of skin will not be as difficult as in the first time. When a material is forced to react in a way, it learns, and starts to react in that way. Additionally, this situation can be resembled with the growth and orientation of creeper. The direction of growth can be dictating to the plant.

2.1.2 Inherent behaviors

Natural materials have action-reaction behaviors. As the ruling authority's of action increases, the influence area of reaction decreases, similar with working logic of Voronoi Diagrams[6].

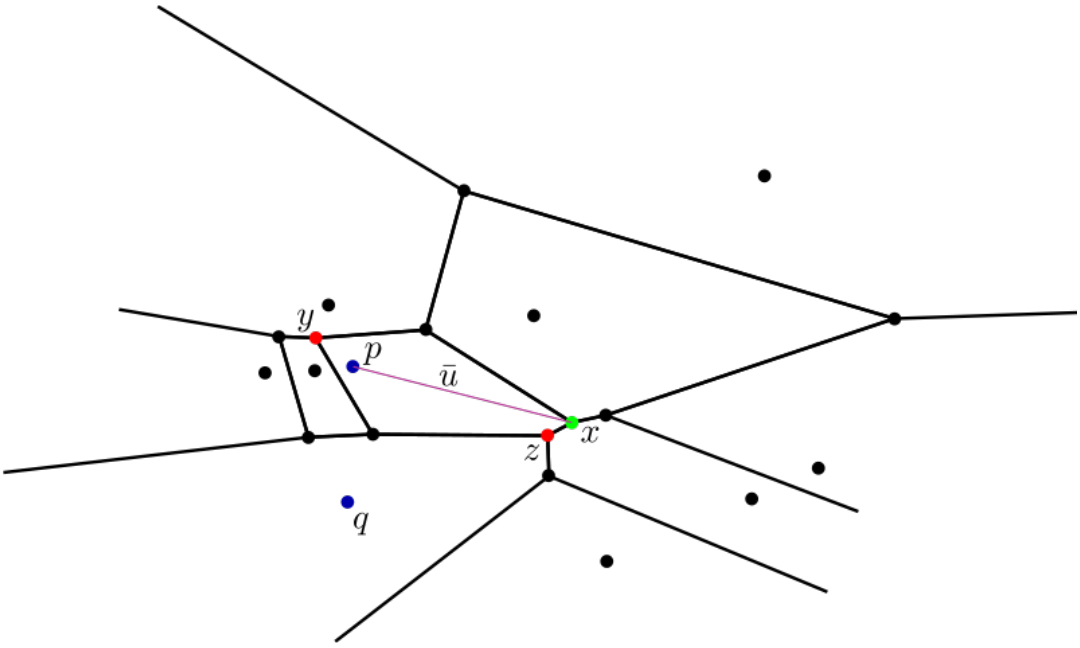

Figure 2.5 : A Voronoi Diagram, which shows the mathematical distances of division and voronoi generator nodes.[7]

As the generators increases, their area of influence decreases and borders emerges according to their situation and topology. Natural materials have behaviors and when

[6]Voronoi Diagram: "The partition of a plane with n points into convex polygons such that each polygon contains exactly one generating point and every point in a given polygon is closer to its generating point than to any other." (http://mathworld.wolfram.com/VoronoiDiagram.html

[7] Url - 4: http://en.wikipedia.org/wiki/Voronoi_diagram, date retrieved 06.04.2014.

combined with other material the influence area decreases or increases due to the specifications of the other inputs of combination.

Complex organisms, multiple decision-making systems and variations emerge via crossing over and combinations in biology. Materials, cores of the materials have the codes of general behaviors. Inherent behaviors, which are genetic conditionings for bio-materials, lead the material to create an influence area because of the diameter of reaction area. Inherent behaviors, makes the material dynamic by sensing the environment and responding. Inherent behaviors and learned movements give the material a power to rule the influence area.

Natural materials have behaviors, reactions and life spans. Thus, natural materials are not completely homogeneous; the reaction that performed can be changed from part to part. Although materials have the code of reaction to an action and inherent behaviors, because of being heterogeneous, the reaction cannot be observed the same way in every part. To reach maximum performance and homogeneous reactions, combinations and reformation must be applied to materials. Maximum performance of material leads to gain desired behavior with less out source and additions. The method of combination, material-to-material or different phases, densities of one single material defines the way of gaining the desired performance, homogeneity and form. This method augments the reaction level of inherent behavior. Setting the reaction level provides a controllable and changeable product.

2.2 Forming Informed by Material

"Form follows function - that has been misunderstood. Form and function should be one, joined in a spiritual union."

(Wright, n.d.)

Cases, limitations, supporters affect design. Either in the abstract computational environment or in the real physical environment, materials have strong impact on shaping the design. Materials in design, affect both intuitive and construction parts of the process. Therefore, material choices have a big role on the quality of thought and products. New research and application areas are not common due to the lack of contact between the intuitive way, scientific proofs and construction. Materials not only have technical specifications in mechanical or electrical feature, but also some experimental qualities. Besides known methods, with a fiction of experimental and rationalist system for materials, new potentials can be obtained, geometric shift emerges, and as Wright, stated form and functions join in a spiritual union. Defining the function must be parallel with form defining process for materials.

2.2.1 Formation, de-formation, re-formation

The morphology of existence, the phenotype of matter is an interactive shape, which is embodied according to environmental conditions, forces. A solid shape has a form and a volume that can be deformed and reformed. Form is the phenotype of a system and the interaction between the form and environment causes morphosis.

D'Arcy Thompson defined form as:

> "…any portion of matter, whether it be living or dead, and the changes of form which are apparent in its movements and its growth, may in all cases alike be described as due to the action of force. In short, the form of an object is a 'diagram of forces.'" (1942)

As Thompson stated, form changes mathematically according to the inherent behaviors of the matter, whether it is natural or artificial. Material can be deformed and reformed under the rules of inherent behaviors. Materials have the inner force of balancing the actions, and reacting according to the physical convenience.

"-de" and "-re" prefixes defines phases of form process. Current situation of form can be demolished, and rebuilt, but the significance is the originality of rebuilding and reforming a part. Materials do not need rebuilding because of they are deformed and reformed. However, the originality and percentage of the reforming is a disadvantage for the material. It is deformed and reformed. A question arises then, how many times can a material react and reformed in the same amount? Reformation phase means that the material is deformed, and this deformation phase wears the flexibility of material. Therefore, in every reformation phase, the material loses its original form slowly, depending to the lifespan of material. Materials have a lifespan that they can perform their behaviors actively. When the lifespan comes to an end, material starts to disintegrate. Composites, which are going to be explained in Chapter 3, are produced to protract the lifespan and give strength in every deformation, reformation. Strength is important because in morphosis, material is not only dealing with its inner balance changing, but also with environmental conditions and forces.

Figure 2.6, made by the author, shows the deformation of a woven structure because of the impact of weight. If the material that is used to create the woven structure is elastic, the complete structure keeps its borders. Therefore, if the borders of the structure were rectangular, after impact, it keeps being rectangular. However, for nonelastic materials, after such impact, the structure looses the form of border.

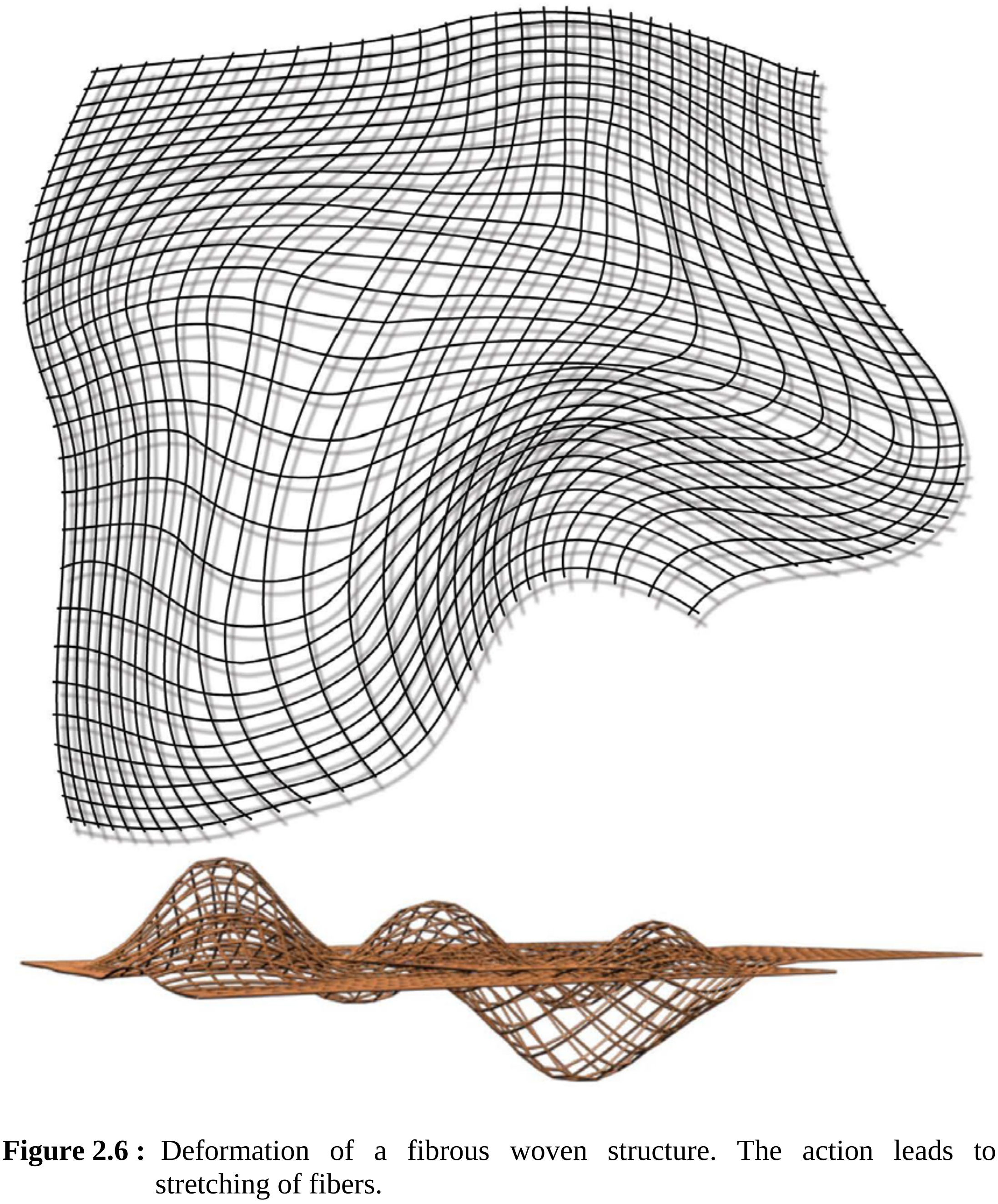

Figure 2.6 : Deformation of a fibrous woven structure. The action leads to stretching of fibers.

2.2.2 Form as a function of material

Form is the physical appearance of cooperative complex systems. Biological, genetic, chemical, physical, spiritual specifications come together and shape the form. However, does every system has its own and specific form? Is it possible to shape systems into different forms? Even for human body it is possible to have different phenotypes with same specifications. Form is only the revelation of current conditions and thoughts, and can be adapted to any other shape.

Fig 2.7 shows 3D printed outputs made up of only industrial sugar. Sugar is used in cubic forms or as granulated. When first checking the images, it seems like a chemical process is applied to sugar, but the sugars that are shown in the picture can be dissolved in tea and has the same specifications with customary ones. The only reason for the shapes is the pouring system and heat of 3D printing. Granulated sugar took these shapes as it has poured through the 3D printer. After creating the digital models for 3D printer, the machine started to print the shapes layer by layer. Sugar is a crystallised material; the printed forms reveal the inner structure of sugar. Although the crystallisation of the outputs are not natural, and made by the force of 3D printer, the final shapes and application technique uses the physical potentials of crystallisation. The figure below is an example of using both material potentials and computational methods.

Figure 2.7 : 3D printed sugar.[8]

The images shown in figure 2.8, figure 2.9 belongs to a study about morphogenetic structuralism. As it is seen on the models, the structure, which is constituted of a single material, is the space maker and the skin covers the system and adapts to the structure. The model is generated in Python Scripting for Rhinoceros 3D modelling

[8] Url - 5: http://www.viralforest.com/3d-printed-sugar/, date retrieved 06.04.2014.

program and the membrane is fixed to the structure by using Grasshopper definition utilized by Kangaroo and Weaverbird add-ons of Rhinoceros.

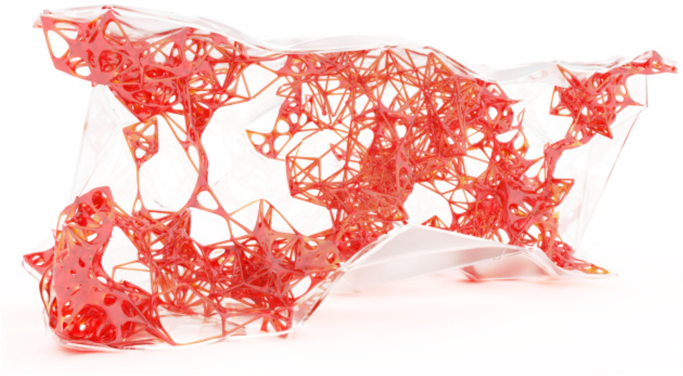

Figure 2.8 : Single material structure, generated by Python Scripting, to express Morphogenetic Structuralism.[9]

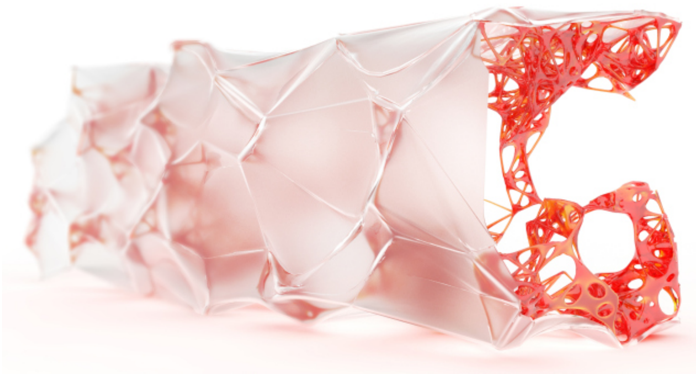

Figure 2.9 : A membrane covers the structure and changes form according to deformations on the structure. [10]

In the animation of the project, the membrane is changing form according to structural deformation. As the structure changes, the form and the phenotype of the designed objects changed. The digital process is manageable through defined parameters. The parameters defined by the designer can be the limits of durability, strength, insulation specification, and interactivity.

Earlier experiments also existed within the field of architectural design that focused on form as a function of material.

[9] Url - 6:http://archimorph.com/2011/10/13/morphogenetic-structuralism-2-00/, date retrieved 06.04.2014.
[10] Url - 6: http://archimorph.com/2011/10/13/morphogenetic-structuralism-2-00/, date retrieved 06.04.2014.

Antonio Gaudi's material based form finding experiments were a vanguard in his era. Gaudi worked with iron, ceramics, stained glass and compressed concrete. As it is seen in museums of Gaudi or in his buildings, he achieved to reach desired performance of the material in many scales. First Gaudi started his experiments with 1/5, 1/20 scaled physical models by using the original material that the building is going to be built.

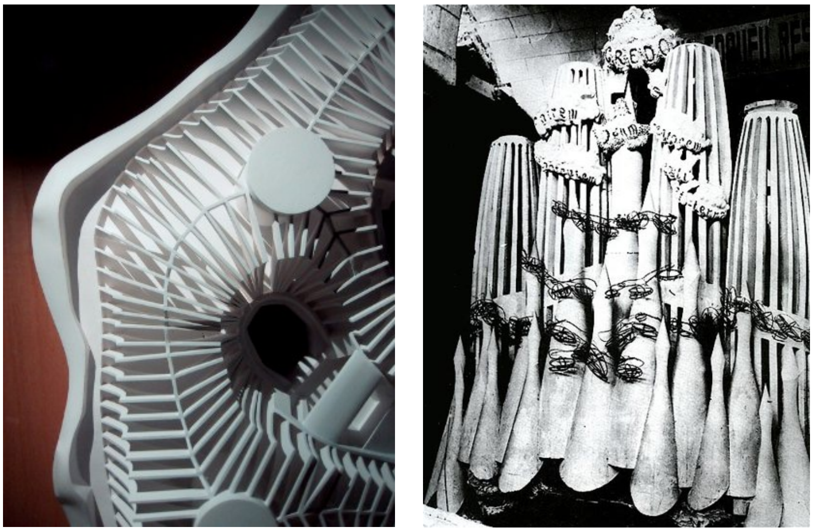

Figure 2.10 : Left: Structure system model of Casa Mila, La Pedrera in Barcelona. Right: A physical model of La Sagrada Familia Entrance. [11]

Examples, given before, reveal the areas of use of materials. Materials and variation of materials gives the soul of the space. A form can have a function not only because of its shape, but also because of the material that is used to create/cover the form. The difference between creating the form with a material and covering the form with a material shifts the borders of design. Materials' functions, properties can create the form according to material's own specifications.

2.3 Strategies for Use

Style of using materials defines the potential and movement area of shape. Conventional strategies allow limited change on shape, however innovative area of use leads to emergent and responsive shapes. Emergent shapes can be gained after heuristic observations of materials. In the case of Façades expecting to be emergent from a façade is not user friendly. As Schön mentioned, designing proceeds in a

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[11] Url - 7: http://casparinstitute.org/Travel/ESP/jour080.htm, date retrieved 06.04.2014.

sequence of "seeing, moving, seeing". The first interpretation refers to see the physical capabilities and observe the material emergence via experiments. Then when moving, the emergent shapes and behaviors should be combined in an order to see again the results of observations.

Materials should be incorporated in the decision-making processes related to both performance and shape. Instead of using materials as mere givens to cover a structure, by observing, seeing their possibilities and making combinations, designs with them and observing the result should be the process to be followed. Every movement, which creates a motion, helps to decrease the shift of shape and move the design beyond boundaries. Moloney (2005) explains morphology via kinetic art:

> "… kinetic art can be summarized as four linked principles:
>
> 1 - There are a small number of basic movement types.
>
> 2 - Basic movements combine to produce composite movement.
>
> 3 - Basic and composite movement, in combination with temporal variables produces sequences of movement.
>
> 4 - Sequence may have a spatial dimension, i.e. the sequence may occur in the same location and/or propagate through space. " (Moloney, 2005, p.70)

As Moloney stated, there are principles for kinetic art. Using these principles as base, there are also principles for material potentials and performance too. Initial principle is observation that leads to recognise the material from top to bottom. After observing phase a database of movement can be generated whether manually or digital. Basic specifications of original material, which does not combined with any other material yet, creates a borderline of capabilities according to which a combination mathematics can be generated. Combination of materials allows for movements in an endless loop due to the lifespan of composite. These movements, which are following each other in a loop, create a motion that allows emergent shapes for the designed objects. Principles of material performance affect this thesis by directing the progression on defined way of principles.

2.3.1 Physical adaptation

Adaptation is a necessity to be involved in a place while performing self-potentials. To continue the action, the object should adapt to the environment. While adapting itself to the environment or balancing the differences, physical adaptations occur due to the changes in conditions. Materials can adapt to different places. Some parameters rule the adaptation limit and type. A material, which has specifications to perform in dry spaces, cannot adapt to wet or humid places. The situation can be exceeded only by combination of different potentials, performances. Composites are performance based, designed and well-thought elements that has a great adaptation potential because of the augmented specifications. Although all composites do not have an augmented area of influence or specification, desired performance can be gained by combining different materials or same material with different densities. On current situation, this adaptation problem is achieved with chemical additions, most of which are harmful for the environment. Although the used material is natural and/or not harmful to environment, some chemicals that applied to material to augment its specifications leads to harmful results for environment.

A material has the potential to perform according to place and adapt itself, but in case of not being adapted an area, combinations helps to exceed this problem. Physical changes, that occur in process of adaptation is generally accepted as a disadvantage of the material, although it is possible to use it as an advantage. By using phase, form changing and responsive materials in a natural way, dynamic and user interacted places can be gained, which allows different using areas.

In this thesis biodegradable material, bioplastics are tested and combined with more bioplastics and/or other materials to reach an augmented response area and to gain a dynamic, responsive design.

2.3.2 Sustainability

The consumption of the sources increase over time due to the demand. Technology is developing and the construction sector is growing over time. Natural sources, which provide the main necessities for life, are decreasing according to the increase of consumption. Buildings require the consumption of a huge amount of material, chemical and natural, to reach the desired form, function, strength. Most of those materials cannot be used after a building, a part of building demolished.

Sustainability criteria are directly related with materials, they have a great role on the continuity of the recycling loop.

In the changing world, façades, elements of the buildings that face with environment are in a renovation cycle. Old, functionless and weak façades are being renewed over time to gain performative and durable façades. Although the sub-systems of the existed building are kept continuing their lives, façades are being changed to catch a contemporary form. Materials that shape the façade should be chosen according to contribute to this fast-changing trend by providing to increase the recycling and sustainability.

Sustainability of façades, leads to a great cycling of material, energy, due to the material percentage compared to rest of the building. Facing with environment is an advantage that can help to increase the level of sustainability by using natural sources. Materials are one of the leaders that should shape the sustainability frame. Not only by being used as a recycled material, but also providing energy saving alternatives, give materials a great potential. Designers should avoid using environmentally harmful materials and/or additions to provide a livable and natural future life.

Not only by being a biodegradable material, but also by providing energy saving performances, bio-plastics are becoming widespread in the changing world. Bioplastics are put to test by the author to explore their potentials as building elements, to contribute the enlargement of using bioplastics.

3. COMPOSITES AND RESPONSIVE ARCHITECTURE

> "Products are generally constructed in layers. Each having its own function. These functions are quite often made invisible by techniques that are applied on a microscopic scale. As a result the products skin, its outer layer is unable to express what going on inside." (Ashton, 2012)

Skin, which consists of different layers of different tissues, is a cover that reserves many specifications behind it. As Ashton states, flexible and responsive, the permeable being of skin is a well designed composite. Every layer of the skin has its own parameters and performances, but at the end, they work together and behave as a whole. Layered systems react holistically. Composites, which are layered, react to environmental changes not layer-by-layer but as a whole. The reaction is the expression of complete specifications of layers that constitutes the composite.

Research on materials and potentials of materials are developing areas of architecture because of their role on the design product quality. By combining conventional design methods and technologic developments, products become more complex. The opportunity of having the same conditions with real environment on computational area, experiments that are materialised in laboratories can also be experimented via computation. Despite all these developments, there is still a gap between design, needs, potentials and technology.

Addington and Schodek (2005) posit:

> All material properties, whether intrinsic or extrinsic, smart or 'dumb' fall into one or more of five categories. The categories -mechanical, thermal, electrical, chemical and optical- are indicative of the energy stimuli that every material must respond to... All energy stimuli are the result of 'difference'. A difference in temperature that produces heat, a difference in pressure that produces mechanical work. Properties are what mediate the difference (2005, p.39).

> For physicists [...] the boundary is not a thing, but an action. Environments are understood as energy fields, and the [material] boundary operates as the transitional zone between different states of an energy field... Boundaries are therefore, by definition, active zones of mediation

> rather than visualising the end result, we need to imagine the transformative actions and interactions. (2005, p.7)

As Addington and Schodek (2005) states, the skin is a transitional zone between two different environments and should be the balance of these two habitats. In order to this, the role of the material is not limited with being a visual object; on the contrary, it should provide the desired and necessary properties for the environments and users, and all materials have a reaction system which is triggered by the differences between spaces, conditions etc.

According to Newton's third law of motion, every action has a reaction that is equal and opposite in nature. Although materials can react to conditional changes such as sunlight intensity, rainwater, cold, hot weather etc., architects and engineers do not use this opportunity as an advantage. Buildings are qualified dynamic under defined parameters, but the dynamism of the building is limited with defined parameters and strict rules. Designers or engineers, decision makers do not let the building to breathe, to move, to response via elements, details of which the building is composed. What if we, as an architect, let the building to be free, dynamic, and responsive just because of the materials that composed the whole? Nick Miller states that in his article, “It was an idea I nurtured for a long time: making the outer layers of a product expressive for its interior, the way it functions and the scientific knowledge that it materializes” (2012). The idea of Miller is similar with Addington and Schodek's that the skin, the outer layer is a transitional zone, an expressive layer for its interior so it is a balance point of inside and outside.

Materials must have one of the main roles on making the building dynamic completely instead of being dynamic on only plans or sections. Again a question arises, is it possible to design the form as a function of material? The strategy to practice responsiveness of materials and create user interactive spaces, new combinations of different specifications, materials should be made. The shift in form is possible with augment the used potentials of materials in design. Not by shaping the material into a defined geometric form, but by using material to reveal its form under some parameters for defined, desired performances. Letting the material to create the freeform according to its possibilities and function under some parameters, creates variations on shape. Material, which is desired to perform responsively, can be created by combinations. Hence composites should be questioned whether they have an augmented perception and response instinct compared to a single material. If so, than, composites can be developed to gain dynamic, responsive and sustainable spaces.

Composites are reinforced and composed of different materials or different specifications. According to Sarah Hovsepian “Composite materials describe any two materials which are combined together in a single bulk material to obtain the best properties from both materials” (2012). Combinations and variations of properties, creates stronger, more elastic, more conductive etc. generations.

Does a composite have to consist of minimum two materials? Is it possible to call a combination "composite", although it consists of one material but with different densities? The point of the composite is to augment the strength, performance, endurance etc. In this case, different densities of a material, if it augments the performance, can be classified as composite.

3.1 Composite as the New Pure: A Holistic View to a Multilayered Material

What is pure is a controversial subject and explanation of purity changes due to the condition. What are the criteria to classify a material as pure or not? Purity is widely used parallel with natural. If a material exists on earth naturally, it is considered pure. Materials, not the synthetic ones, are existed naturally; they are not produced on laboratories although they are refined before using. As it is stated in before according to Hovsepian S., composites are basically composed of two materials which combined together. After talking about purity, can composites classified as pure elements, depends to their natural aspect? New questions emerges under this condition, "Is composite the new pure?" or "Are composites actually pure?"

Composite materials are combinations created to achieve desired performances. Natural materials can react to some actions. So do composites. They are composed of different materials or different specifications such as density, color, physical phase, of one material. Although natural, unprocessed materials have action, reaction specifications, due to not being homogeneous and strong enough for some conditions, they cannot reveal their reactions apparently. While using conventional and naked eye methods, generally, it is nearly impossible to observe the change on the material. Thus, inherent behaviors are relative and not exact, there is not an exact answer to "How many times can a natural, pure material react in same way, or how many times can it react?" It depends on its life span. As the actively using time passes, the amount and size of reaction generally decreases because of being natural and having a lifespan. Composites are the combinations that have balanced reaction, which does not differs every time for a specific action.

Composites have specific aim, which is the decision maker of which material to choose. Different specifications, materials come together to provide the defined performance although they have different qualifications on their own. Composites have layers and on every layer, they have different characters. The layers of materials reserve many potentials. They can be used to achieve performance based material systems that has augmented inherent behaviors instead of being chemical and environmentally harmful. In dictionaries, the word “composite” is defined as, “a material made up of more than one substance that is used for building things” (Cambridge Advanced Learner's Dictionary & Thesaurus) and "made up of disparate or separate parts or elements; compound" (dictionary.com). “Composite Material” is defined as, “Two or more distinct materials that do not merge (do not lose their individual identities) but still impart their properties to the product resulting from their combination.” (Business Dictionary). According to first and second explanations, the purity of materials, composites is not a subject to think on, because explanations refers a composite is consists of layers and they all have their own behaviors. If the layers do not behave together and do not create, a new performance and they are completely interconnected parts, than there is not any necessity to create a classification like composites. On the contrary, third explanation expresses that materials do not merge but as a result, they perform together. This collective performance, motion creates new potentials and dynamism. The situation can be explained with an example, which is based on grammar system and structural system of languages.

Language is a living organism. Additive languages have suffixes and prefixes, some of which only makes the original word more specific, and the others completely changes the original word. The shift of the word is similar with materials, chemicals and composites. Composite materials have layers, which gives more specification to the material. Working as a whole and having a homogeneous performance is composed of combination of layers each of which has different character.

To sum up, composites consist of layers, which can be either of different specifications of one material or of different materials. Composite has behavior of itself, while the constituent layers have their own specifications, but perform together. Behavior creates the performance. Although every layer of a composite has its own specification, they are combined together to perform the general behavior of the composite.

3.2 State of the art

Although composites are widely in use, the qualification and application variety is poor for composites. As the technology develops, to manage composites and calculate the performance became easier, but the application and design process is still driven by conventional techniques.

Composites can be used as a way of revealing the idea behind the designed object, product. Although design has versatile and flexible aspects, the application process limits the flexibility of design. With the development and shift in technology, composites are being developed and designed to break the rule of rectangular hierarchy of building design.

Computational materials, composites and material based designs are ongoing processes, which are expanding. Several experimental studies are performed by architects.

Manuel Kretzer, researcher and tutor from ETH Zurich, chair for Computer Aided Architectural Design, has established a *materiability research network* that connects students and researchers interested in material studies from all over the world. Kretzer is working on the notion of a soft and dynamic architecture, created through an experimental use of new (smart) materials. One of his works, which is called "Actuated Matter", is based on the application of smart materials in architecture with respect to their ability to transform architecture into an "Emotive Environment", a space that relates to its inhabitants in an emotive and responsive way. (Kretzer, 2012)

He is questioning, how we could incorporate aspects of organic systems within the new materials and new architectures.

Figure 3.1 : Actuated Matter product from the same named workshop by Manuel Kretzer, CAAD, ETH Zurich.[12]

Neri Oxman, who established the Mediated Matter Group at MIT, works on material-based design computation. One of her projects, Subterrain explores the notion of material organisation as it is informed by structural load and environmental conditions. An object oriented finite element application is used to determine material behavior according to assigned properties and performance such as stress, strain, heat flow, stored energy and deformation due to applied loads and temperature differences (Oxman, 2007).

[12] Url - 9: http://materiability.com/actuated-matter/ , 06.04.2014

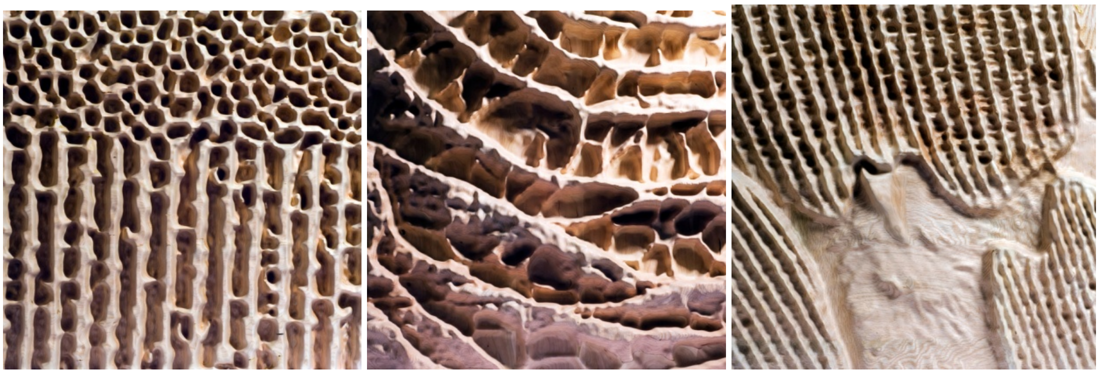


Figure 3.2 : *Subterrain* observes material organisation informed by structural load and environmental conditions. (Oxman, 2007)

The shown image above, figure 3.2, is the outputs of *Subterrain* work by Oxman. In this work, Oxman inspired from the structural organisation of butterfly wing, a leaf section, and visualised it. Wood is used to express the final output. The physical model is created by CNC milling machine layer by layer. However, to get the desired form and performance different typed and specified woods are used. This is an example of single material composites, because of being different specifications of same material, wood.

Before these projects, materials and potentials were working by Gaudi, Fuller, Prouvé and Otto as is stated in Chapter 1. The projects mentioned above are a part of an ongoing research domain, which tries to explore the potential of material and shape generations by using computational methods. Simulations, real world behaviors can be generated by using CAD tools. Computational modeling helps to augment the variations of forms and defines the physically allowed limits of movement capacity, which makes the researcher aware of possibility of reaching the desired behavior of design.

3.3 Multidisciplinarity in Composite Materials

Architectural design is a multidisciplinary system. Technical, inherent specifications of materials allow us to enlarge the design area and achieve different designed objects. To reach innovative products, the practice should not only based on design but also should be based on engineering, which leads the design to be more efficient, economic, sustainable, responsive etc. According to Kolarevic, " By integrating the design and analysis of buildings around digital technologies of modeling and simulation, the architect's and engineer's roles are increasingly being integrated into a relatively seamless digital collaborative enterprise form the earliest, conceptual stages of design" (Kolarevic, B., 2005). As Kolarevic states, design and engineering phases should be co-operative branches. As the technology develops, it has been easy to test static, dynamic, design and technical specifications in only one model. Simulation technology allows reaching final performance of the system. BIM, Building Information Modeling techniques allows performing both intuitive part and technical part of the design, construction process.

Free form is possible with technological developments. The shift of the form has a link with shift of the technology and the application of design. In the ancient years, as it can be understood from the drawings and historical buildings, designed buildings are framed by a grid structural system. Technological developments can be applied to the design by collaborative work of engineers and architects. Kolarevic B. states that "To catch the free form, architects and engineers should work together from the beginning of the project" (2005). Kolarevic is also mentioning about different disciplines in his book and defining the collaborative work as to speak the same language with different disciplines.

Sevil Yazıcı defines cooperation in architecture and the method of working as top-down approaches. According to her, after generating the form as a first phase:

> The secondary specifications are, respectively, the structural system, materials and details as engineering solutions in the later stages of the design process. Every single modification that occurs in the later stage of the design process affects the overall architectural scheme, in which the architectural designer moves back and forth in the design process. (2011)

As Yazıcı stated, beginning from the design process and developing the project in an order, causes the architect to turn back to initial phase because of lack interconnection. She offers to use bottom-up approach, such as computational design, instead of top-down approach because of the necessity of seeing the process as a whole. Holistic approach should be followed to solve the problems from all aspects and to trigger the computational generation phase by providing a well-organised system.

Buildings in use have limited and same response that generally cannot be observed with naked eye or human scale to actions. Heating is the same in every level, luminance, façade; insulations are the same on whole building which limits the users. If the façade can change according to different situations, than the variation of use and dynamism of building can be observed. Nowadays, smart buildings become widespread. Engineers make the building “smart” by automation systems, which are independent from design. Smart systems completely based on engineering solutions and do not interact with design. Materials can be the solution for the lack of contact between engineering and architectural design. If designers and engineers design the material not as a layer but as a system, the results become various. Multidisciplinary allows the systems be more free both architecturally and engineering. For example, it is possible to luminance the façade of building with different amount of light. However, if engineer design this as an engineering solution it will be independent from the user. Architects and engineers should think about the system together to get an interactive output. If there are some users on some levels of the building, a heat sensitive or movement sensitive system can understand the areas and make the façade different according to areas that are being used.

3.4 Generating Composites

Experimental approach is being used by different disciplines and consists of trial and error method and outputs of the iterations. Experimental architecture is a kind of search for “the new”, and in developed levels many design can be generated via technological devices and computation. Material experiments have strict borders and limitations of physics, therefore the results are numerical like the resistance of the concrete or the ductility of steel. Instead of exact knowledge-based and controlled tests, rational and randomly proceeded experiments can be combined with the known specifications of materials, and new patterns, work areas can be found. The invention of reinforced concrete is based on needs. First, it was used as a concrete vase for plants. However, as the plant grows, because of resistance specification of concrete, it cracked. After that Joseph Monier, the principal inventor of reinforced concrete, combined concrete with steel and obtained today's most commonly used and durable composite, reinforced concrete. Out of composites; materials itself generally have potentials inside and experiments are the best way to invent them. Conductance, expansion, shrinkage, and physical formations can be emerged in some environmental conditions.

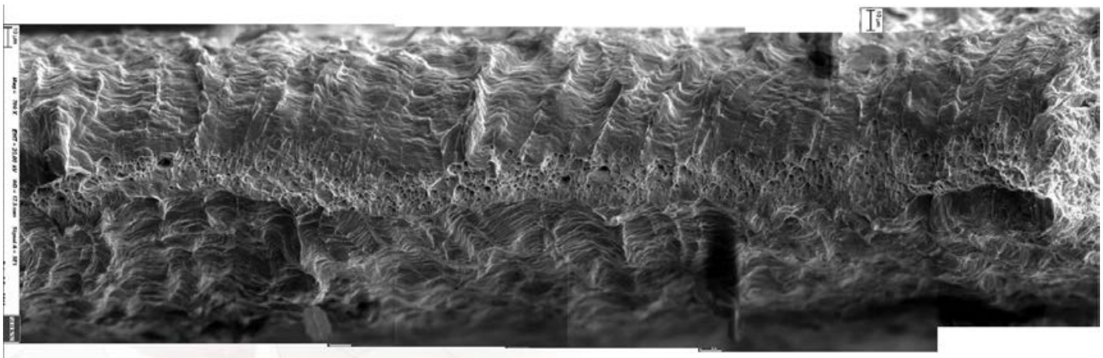
The importance of layers in composite materials defines the frame of capabilities of the composite. Because of the dynamics, elasticity and strength of the layers composite can have different movement and reaction capabilities. Therefore, the layers must be organised due to the defined parameters and expected behaviors.

The difference between material possibilities and shape as well as structure possibilities also play a big role in composites. The pattern of wire elements, the thickness of layers, and the direction in which some materials are used allows elements to move in different ways. If material itself does not have tensile strength, additional materials lead them to resist to tension.

While thinking about material potentials, the problem of the composite emerges, generating composites. Generating composites is based on needs and conditions. By creating a database of specifications, a crossing over phase can be generated both manually and digitally. CAD/CAM technology, which is widely in use, is one of the main characters on generation phase. CAD, Computer Aided Design and CAM, Computer Aided Manufacturing allow to create iterations of any situation and produce it. After making physical models, more iteration can be generated with same environmental properties by using CAD and with the relation between CAD and CAM, the iterations can be produced.

Logic of a composite is based on creating a performance by combining different specifications. “Different specification” can be different materials or performances. To obtain the desired performance a mental mixture of potentials should be combined. One single material can also be used as a composite, under these conditions. By strengthening the defined specifications, a well-designed and working composite can be obtained.

Functionally graded materials are an example on single material solution to composites. Functionally Graded Materials (FGM) are advanced composite materials which is produced to have graded variation of the relative volume fractions of the constituent materials (Cantergiani E., nd.). As it is shown in the fig. 3.3, on microscopic scale, functionally graded materials have a heterogeneous organisation to provide the desired performance.



$$q = \frac{A_0 - A_f}{A_0} * 100 = \frac{0.193 - 16.81 * 10^{-3}}{0.193} * 100 = 91.29\%$$

Figure 3.3 : An example of Functionally Graded Material, which is shown on microscopic scale. (Cantergiani E., nd.)

Fig. 3.4 and Fig. 3.5, shows the general specifications of functionally graded materials, the working principals and comparison with conventional composites. Conventional composites have a regular distribution of materials, constituents; while a functionally graded material has a heterogenic distribution to provide the necessary performance for the application area.

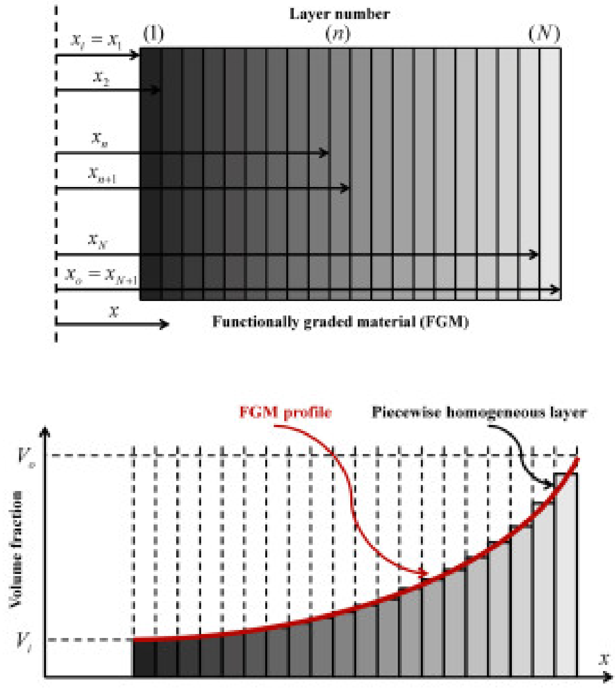


Figure 3.4 : Volume and working diagrams of Functionally Graded Materials.[13]

[13] URL - 10: http://pasini.ca/research/track-one/multiphysics-models-for-functionally-graded-materials-including-graded-cellular-solids/, 06.04.2014

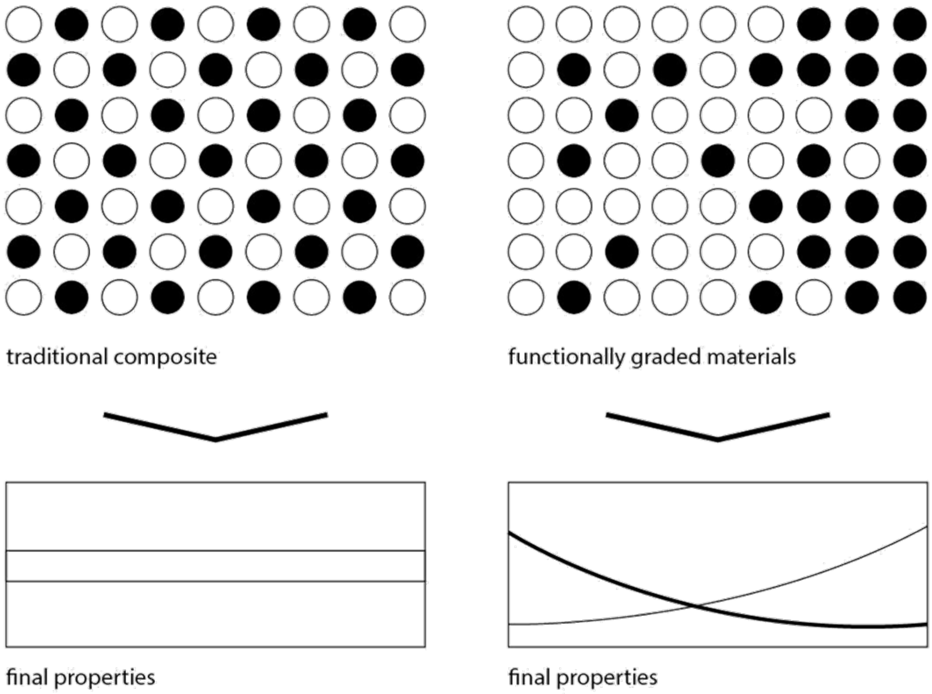


Figure 3.5 : Comparison between traditional composites and Functionally Graded Materials (Cantergiani E., nd.)

As it can be seen in Fig. 3.5 FGM's specifications can be changed by arranging the density of constituents. In this thesis, the façade system is set on to an idea that questions the performance of composites created to be responsive by using material properties.

To sum up, generation of composites differs due to the technology and desired performance. By collaboration of different disciplines, it is possible to both produce a composite for a specific reason and an adaptable composite that can be used in various areas.

3.5 Responsive Façade Design

Façade is the most interactive element of the building. Similar to body skin, façade is a border, a transmission surface between different specified environments. Most of the energy loss, heat transmission occurs on façade. Therefore, performance of the façade nearly defines the using area of the building. Heat insulation way can explain this issue. Generally, for office buildings, insulation layer is located inside the façade, exterior wall to provide easy heating and cooling. For the housing units, buildings it is reverse. Insulation layer locates out of the exterior wall. The logic is to heat the wall during the daytime, and try to keep the heat on the same level in any hour of the day.

Façade is one of the biggest elements that have a high percentage on building performance, and it is the only one that should be aesthetic as well.

3.6 Interactive Façades and Material Computation

Behaviors of materials and the unexplored potentials of them is a progressive process. By combining these behaviors with computation, it will be easy to generate reaction patterns. Instead of framed world of some material based works, jump into the experimental process lead to obtain user or nature interactive and sustainable outputs. Achim Menges (2005) states that " Understanding of form, material, structure and environment not as separate aspects, but rather as complex interrelations that are embedded in and explored through integral computational process." Different components can be used in same system and fictionalised together, and this complex interrelation can be solved with computation.

Designed object, building or system has some behavior due to the environmental actions. Inherent behaviors make the system sensitive about some subjects. For defined problems, these reactions can be enhanced by combining true compounds. These compounds do not have to be different materials. Different phases, shapes of the same material can also enhance the responsiveness of the system. Material should be used both with its structural properties and with physical possibilities.

Shape, structure and pattern play big role on performances especially for fibrous materials. The pattern they have leads them to be strong in some parts and weak in the rest for heterogeneous patterns. For homogeneous materials the structure and shape gives them strength. They give the strength to the materials.

Physical and digital experiments should feed each other to increase the final performance of the work. Computation differs from the 3D modeling because of having different information than 3D models. Thus, materials are being used like the logic of 3D models, in real world, this thesis aims to change the point of view to materials. They are not only visualizations of any form, but they are performance-based constituents of a constructed item.

By combining material properties and computation, it is possible to procure a responsive, user interacted element. Moloney states in his book that "It is proposed that the distinguishing aspect of kinetic façades lies in patterns of motion, which arise from the movement of multiple parts" (2011, p.69). Motion of the façade, a kinetic façade is parallel with moving parts. Movement of the parts creates a motion, a pattern for the façade, and the movement of the part can be provided by interaction between users and components. Bix, light and media installation of Graz, Kunsthaus is a performative façade design, which is one of the biggest application. Edler (2005) explained this media façade in Performative Architecture Beyond Instrumentality as:

> It transforms the main eastern façade of the building into an alterable, performative membrane to transmit internal processes of the art institution to the public. It is an attempt to create an experimental laboratory for the development and deployment of a unique urban communication style - a "language"- which is synchronized with the architecture and its users on the one hand, but which is also deferring to its urban context on the other. (2005)

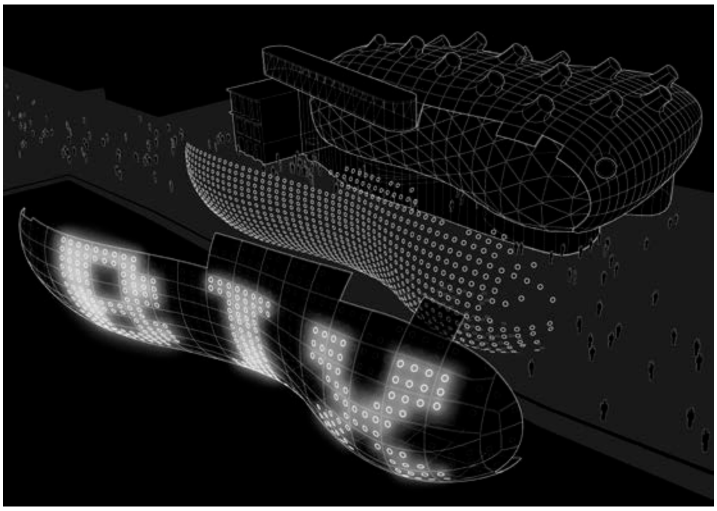


Figure 3.6 : Kunsthaus, Graz - Media Façade (Kolarevic, B. 2005)

Out of being a performative façade, Bix is a media façade which consist of acrylic glass and a matrix of 930 fluorescent light rings located on an amorphous surface. Materials can be used instead of electronic systems or with electronic systems to be a performative element, instead of being a media façade. Components are consist of materials, composites. By using interactive composites, composites can be in an interaction with users. The system is possible with buildings automation system, but materials also have the inherent behavior of response.

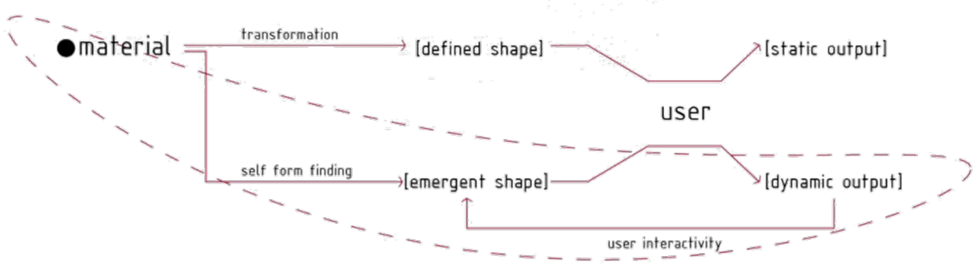


Figure 3.7 : Relationship of user and application type of material. (By the Author)

Figure 3.7, which is created by the author, shows the application, using alternatives of material and the results. As it is stated before, to reach interactive spaces, products, materials should be used actively. If material is shaped according to desired form and limited by parameters, the relation with user creates only static outputs, which is not interacted with the user. In this type, the space has its own and restricted shape, and it does not allow the user to be in a relation with constructed output. On contrary, if the application method goes beyond borders and lets the material to shape itself by self-form finding, than the final shape emerges. The allowance of creating its own shape should be controlled by some parameters to provide the necessary life quality. The emergent shape of form finding phase is a dynamic output because of the interaction with the user. Hence the material is not restricted to behave as a prism, after every interaction, a new emergent shape is formed and this loop can turn into an endless loop until the material, the composite expire its lifespan.

"Computation is in principle information processing and is by this definition not limited to digital processes, but also encompasses material models, where a substance is set to process information" (Terzidis, 2003, 65; Stepney, 2008).

Computing is a way of ruling, nowadays. Because of being capable of releasing real environmental conditions and in some cases easier than real experiments, most of the generations are being shaped on computers. Via parameters and rules, it is possible to have the results of the issue. However, as Terzidis stated, computation is not limited to digital process, computation differs from 3D modeling or 2D drawings by combining different information, such as materials, behaviors etc. Computation allows managing the information of different disciplines.

Computing allows managing many systems. Simulations are the best ways of observing a process and results. By using real time conditions, realistic solutions can be gained. As architects, we are using computers not only for drawing but also to structure a design definition and system. Material researches, final patterns and performances can be simulating on computational area. After defining the expected performance of building element, variations, expected shape grammars can be generated on computer. If the programmer or the architect knows the basic performance, the specifications can be load to the material behaviors on computational area, because of it is possible to see the results of some combinations on virtual area the researcher can get many outputs from the iterations of experiment.

Kolarevic (2005) states that about the computational tools, "Computational tools are clearly gaining ground in a variety of uses and their practical applications in many areas of building engineering design are helping to push the boundaries of quality and complexity in architecture and infrastructure". Defined forms such as prisms and cubic or spherical forms, which are Euclidian geometries, can be test easily, while complex forms, which have complex algorithmic and mathematical explanations requires huge information to simplify. Computation and visual tools allows us to manage those complex mathematical performances.

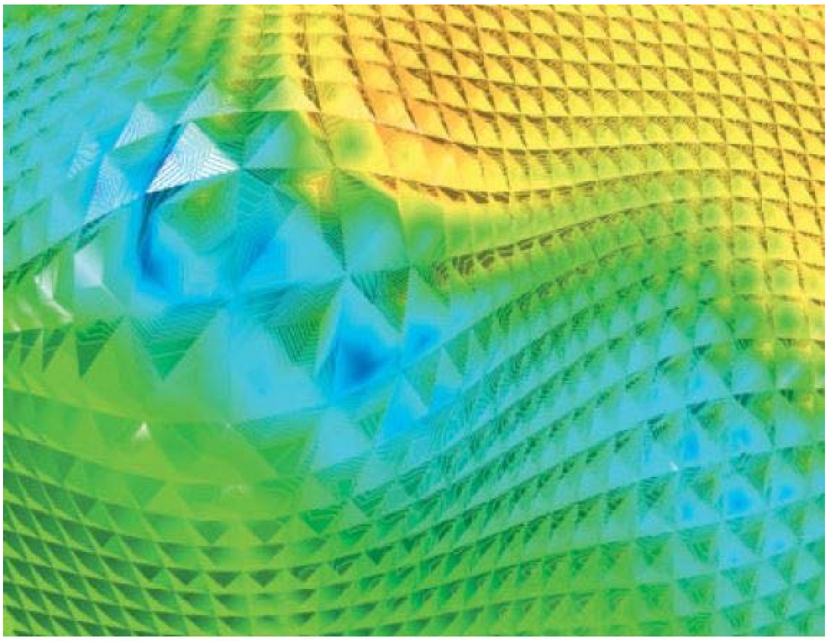


Figure 3.8 : Fluid dynamics generated by computation can also be instrumentalised to explore and strategies the performative effects of material systems (Menges et al. 2008, p9)

4. DESIGN OF A BUILDING ELEMENT: FAÇADE

Building element design is a part of defining the performance of the building. The elements that constitute the building have the main role on function. Therefore, the details should be well designed. When the state of the current construction style is analyzed, conventional systems and solutions have high percentage. Materials, composites are used often but not in an innovative and fully beneficial way. A question arises than, can we use a building element instead of another one? Can we accelerate the performance of the material by using well-designed and responsive composites?

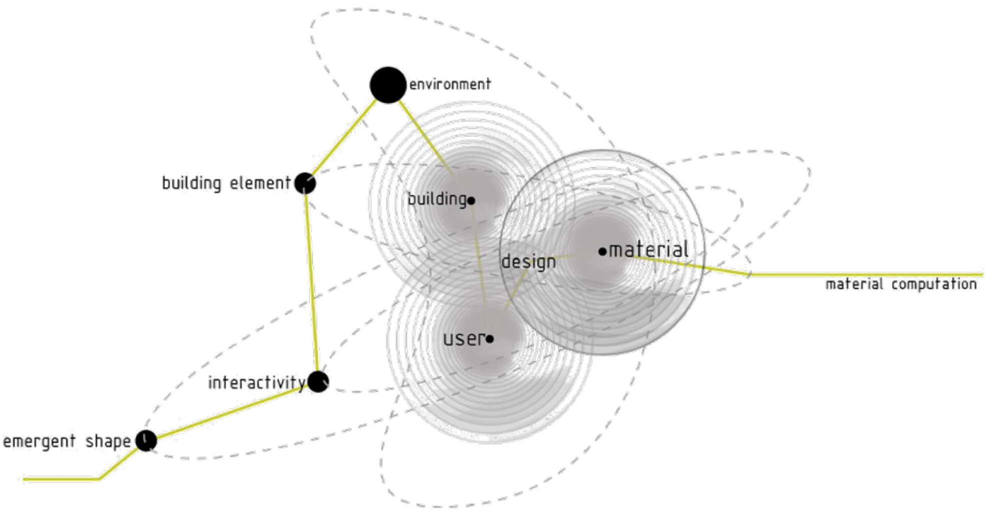


Figure 4.1 : Relation of material, environment, building element and users. (By the Author)

Figure 4.1, which is drawn by the author, shows the relation of constructed environment dynamics. Design is the intersection of physical existence of building, material and user. According to the schema, if material, user and design creates the interactivity and interactivity of these inputs creates the emergent shape. Building element is directly related with material, design and whole building. All these entities are items of environment and after defining the parameters, movement levels; the system can continue to evolve via computation.

4.1 Building Systems and Sub-systems

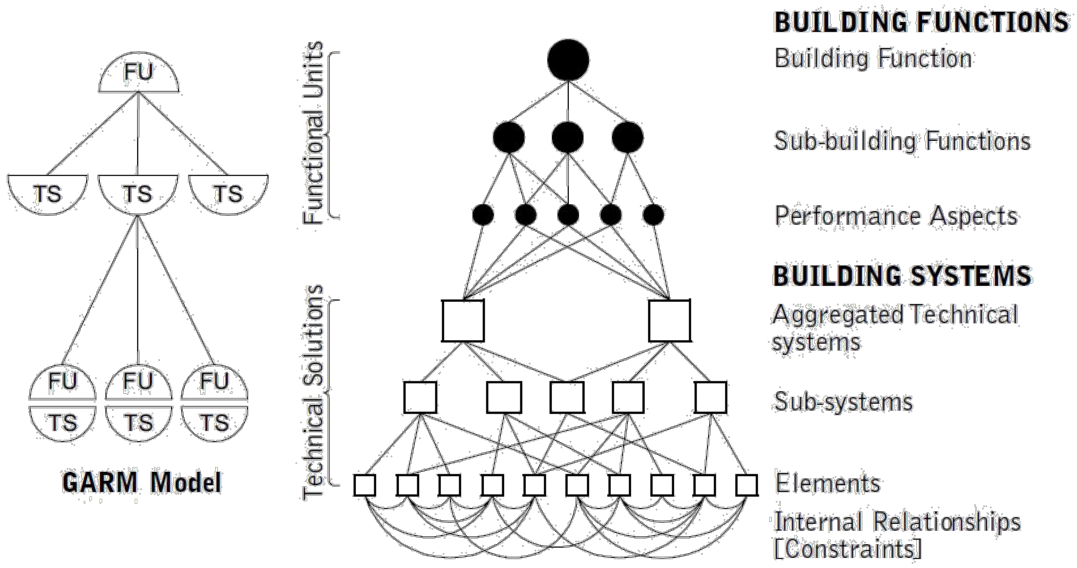


Figure 4.2 : A frame work of building systems classification (Augenbroue, 2005, p101)

Figure 4.2 shows a framework of building systems classification. Augenbroue, who created the shown framework explains the building systems in some subsystems as:

> There is no established theory for the discovery and definition of PIs. Wim Gielingh in his General AEC Reference Model hypothesizes a design process in which the design problem is reduced into smaller manageable functional units (FUs). For each of these FUs, a designer looks for a technical solution (TS) that satisfies the functional requirements of the FU. When no solution is found, the design problem is restated with a new solution is developed to meet the functional requirements. Solutions to more complex design problems are obtained by reducing the design problem into smaller design problems. (2005, p.101)

PIs refers to performance indicators in this definition and General AEC Reference Model is GARM Model which shown on the Fig.4.2. According to AugenBroue to solve the general problem, the whole should be divided into smaller units and for every unit; there will be a technical solution to accelerate the performance of the whole. Similar with inductive method, GARM Model defines the problem from the smallest unit and by solving it technically, applies the solution to the whole by changing functional units.

Building elements are functional units, which constitutes the whole and to gain the desired performance they should be observed and designed carefully. Augenbroue continued his argument by explaining, building elements' interaction which belongs to different building systems. A building element not only affects the system that it belongs to, but also affects the whole system. Augenbroue continued the argument as:

> The lower half of figure [...] shows the aggregation of technical systems from subsystems, until we reach the level of the well know major 'functional systems,' such as lighting, fire safety, etc. These systems contribute to one or more of the required building functions. Elements are the smallest decomposition of a building system and may belong to one or more subsystems. There exists a constraint relationship within elements of a system and between elements of different subsystems." (2005, p.101).

The process of building element design includes both micro scale and macro scale. While designing the element, the performance of the element affects performance of the building. The system is like words of a sentence, to express the right subjects, proper words would be chosen. Expected behaviors constitute the main character of the element. For which conditions is that element going to be used or is augmented, area of use necessary questions defines the border between conventional building elements and innovative building element.

Exact expectations from a building element, leads the element to serve to limited conditions. Augmented expectations and tasks triggers the design phase and innovative solutions emerges. Materials and the possibilities support this innovative solution phase and help to improve the performance of the building element.

4.2 Expectations From a Building Element

Building elements should both provide necessary specifications for the performance for which it is going to be used and provide relation with other elements. Materials have relation with environmental and physical specifications, so the answer has a link between chosen materials' behaviors and limits. However, to accelerate the performance of building element, composites should be generated to intensify the response and movement amounts of materials.

Façade is the most active building element in relation to multiple factors such as users and environment and thus the focal point of the study at hand. It is deemed suitable to challenge the use of materials innovatively as the element that interacts with multiple conditions while having a strict relation with structure. According to

Moloney (2011), "Once the skin of the building became independent of its structure, it could just as well hang like a curtain or clothing." (Moloney, J., Designing Kinetics for Architectural Facades State Change, p.42). As Moloney stated, façades should be designed in case of being in a relation not only with environment and users, but also with main structure of the building.

To understand the basic, general working principle of building elements, some parameters of performance expectations can be itemized such as:

- Durability

- Strength

- Insulation, according to location

- Being in an interaction with other elements, working in an harmony with other elements etc.

Mentioned performance expectations draw a border except for the final one. Being in an interaction with other elements and users, allows being dynamic, and needs computation to solve.

4.3 The Architectural Performance of a Façade

Façade, skin of the building, is an interface between outside and inside. Buildings consist of elements that perform positively for the user benefits. The user is generally limited with the building users, habitants. Although buildings have an obligation to be both user and environment friendly, generally they are not being designed according to consider both inside and outside. Façade finishes are all interfaces. Interface means a transmission between two environments; therefore, the biggest element of the building should care about both faces.

Performance parameters changes due to environmental conditions and façade can be designed both dynamically and statically. Dynamic façades adapts to different conditions and they perform according to users. The borders, opacity, permeability are controllable. This specification of dynamic façades supports the parameter; being in an interaction with other elements, working with an harmony with other elements, by being adaptable and controllable.

Out of being responsive, it is beneficial to research façades, which are being applied today. The examples, is chosen according to being performative which is provided by a structural system and additional systems.

Different façade systems exists especially in architecturally developed and new constructed cities. Unlike static approaches, dynamic buildings have interactive, responsive, façades due to technological developments and needs of being adaptable. Not only façade systems, but also shading systems can make the appearance dynamic and interactive. The examples below (figure 4.3) are consist of panels and the motion of the façade is not caused by material. Electronic systems or environmental forces such as rain, wind etc. leads the façade to perform.

Before making an experiment about material potentials on façade, it is beneficial to make a survey about dynamic façades and movement capabilities of independent components. By combining these motions with material performances, different patterns can be emerged.

In order to compare the performances, first two images are examples of static façades, of which materials are shaped according to defined shape. Rest of the examples, except last two; represent the dynamic appearance of performative façades, which are based on mechanical systems. Last two images show the dynamism and response capability of materials which are used to design the façade dynamic without using any mechanical system and/or automation. Materials response to environmental changes and creates a motion by combining the response movements.

Figure 4.3 shows seven images by Moloney for façades based on different studies.

Images, numbered 1, 2, 3, 4, 5 are examples of performative façade, based on mechanical systems that gives the motion to façade according to environmental conditions such as wind and/or sun position. First image is an analytical drawing of adaptive shading for Ciudad de Justicia in Madrid (Moloney, J., 2010, p.15). Each hexagonal part of the façade has an independent motion, which leads to non-uniform compositions. The movement of hexagonal components creates a motion and pattern on the façade. Second image is an analytical drawing belongs to Moloney (2011), of a performative façade, which consists of panels, have rotational movement in all three axes. The rotation leads the façade be performative and create different patterns. The rhythm of the façade depends to the link between panels. They can move parametrically of independent from each other. Third image is a drawing of Battleship designed by Anthony Howe, 2006. Similarly to second image, rotation of the component allows the system be performative and dynamic according to force.

Fourth image is a Pneumatic Quilted Façade by Ho Sun illustrated by Moloney (2010). The component, a pneumatic pillow, swells up randomly and a wide range of kinetic patterns emerges according to the expansion and contraction. The whole system is connected to an airlift pump that pumps air to pillows. Fifth and sixth images shows Hyposurface, designed by dECOi. The system is consists of metal leaves which moves in a triangulated plane. The façade is capable of producing abstract or figurative relief. The applied image of the project is shown below; shows that the metal leaves are being used both for form changing and for color reflecting. The idea is based on mechanical pistons system that controlled by computation. The censors recognise the user and create reaction to it, however the motion is being generated by computational tools instead of being manual.

Seventh image is representing the material properties, which are triggered by environmental conditions. The properties response to the environmental changes and create a motion which consists of movement loop. Seventh image is the analytical drawing of responsive timber surface is an example of spatial deformation through controllable variance in material property. The system shows the shape memory of a timber component which responses to environmental conditions and creates a flexible, form changing, dynamic skin. This façade is directly shows the material behaviors and the motion is created by the movement, deformation and reformation of the material, itself.

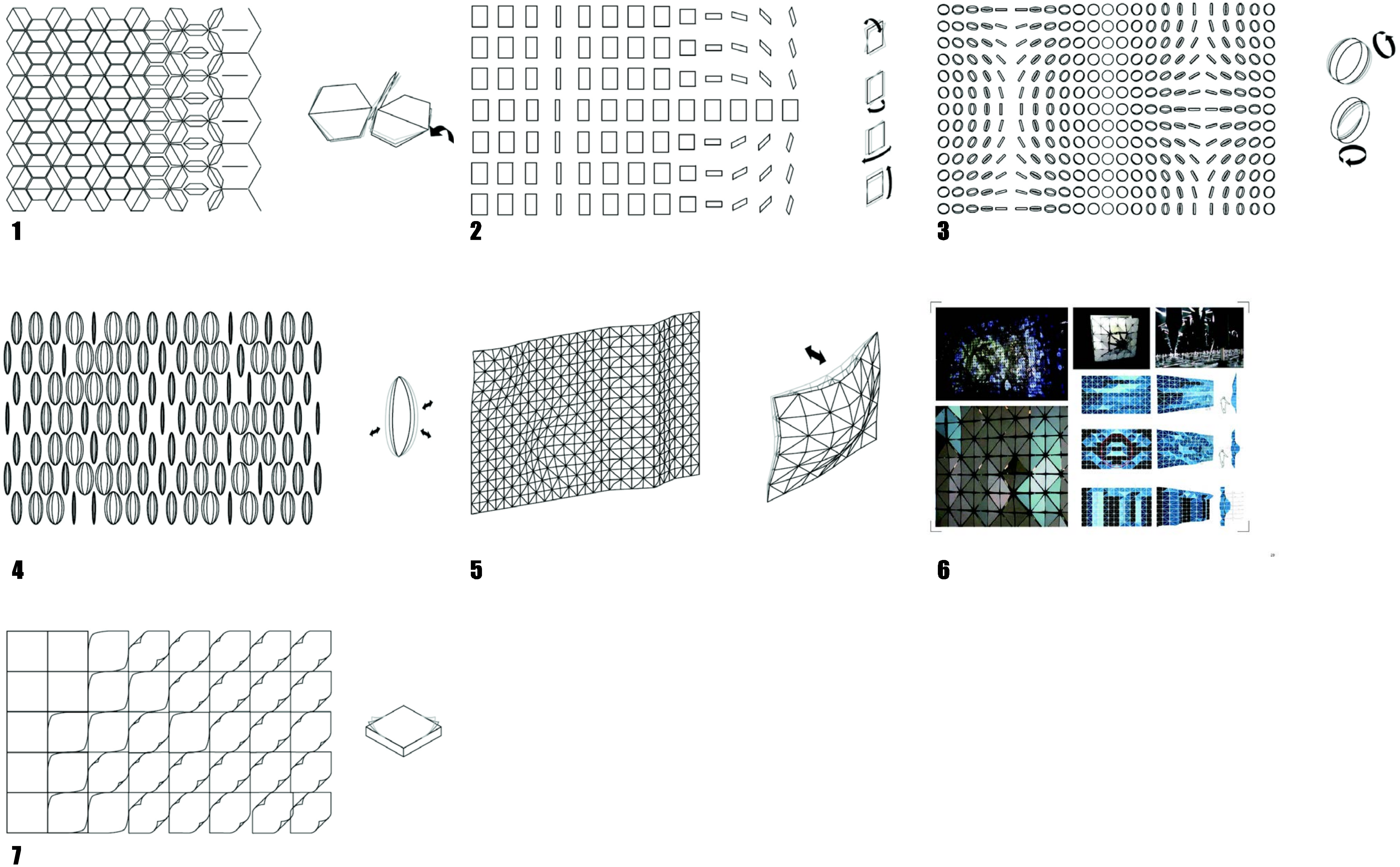


Figure 4.3 : Analitical drawings of different façades by Moloney (Moloney, J., 2011)

4.4 Physical Flexibility in Composites

Composite varies according to functions, shape, visual specifications, layer systems etc. Thus, physical performance of a composite is the main issue, it should be defined according to the dynamism of desired performance.

Flexibility allows for changeable spaces. Although border, as a word, sounds rigid, flexible materials break the rigid form of the border. By using flexible inputs, the variation of output decreases.

As it can be seen from Chapter 4.3, façades can be physically flexible and adaptive by using mechanical systems. What if they can also be flexible because of material properties and inherent behaviors? The façade that is going to be materialised and computed in this thesis, performs its motion by being flexible because of the properties of material, bioplastics. To reach flexibility, the inputs of the composites should be used according to the physical necessities of being flexible. Being flexible is directly in a relation with softness. Soft materials, composites reveal flexibility specifications more than solid ones.

Physical flexibility exists, naturally on some materials, but both to increase the flexibility and expansion level and control the shift, composites can be used. Composites are more controllable while being more flexible at the same time. Composites are a way to create motion based on material properties and responses. By designing the way of combination, the response capability can be released or hide.

5. A FAÇADE WITH A COMPOSITE

The project that is held in this thesis is consisting of three main parts; physical experiments of bioplastics, creating performance based combinations, digital simulation of the designed system. After collecting data about materials such as timber, plaster, glass, from initial phases of material researches, to study on elastic material is decided. Thus, elasticity of materials can be set up to the mixture of composite; bioplastics are chosen due to the elastic and solid performance of it and representing a general behavior of elastic materials.

5.1 Bio plastics: Potential as a Composite Building Element

Bio plastics are biodegradable polymers, which has minimum negative effect on the environment. Unlike petroleum-based plastics, their carbon emission levels are very low and bio plastics can dissolve in the nature easily. The period of dissolution depends on the proportion of ingredients.

Bio plastics are made of starch, or vegetable peels, which are rich of starch. On 2013, a high school student Elif Bilgin, from Istanbul won the first prize of Google Science Fair by producing a bio plastic by banana peels (Google Science Fair, 2013). Thus, banana peels have high proportion of starch inside, it is a good solution to use banana peels in recycling.

Bioplastics are classified as composites in this thesis because of consisting more than one material and possibility to change the properties of final material. Bioplastic mixtures allow the material to reveal different properties such as being soft, solid, rigid, fragile, sticky, liquid etc. By combining those different properties of a single composite material, bioplastics; new performances can be gained.

5.1.1 Overview of bioplastics as architectural elements

Bio plastics are becoming widespread because of being biodegradable, sustainable, cheap and being in different phases according to amount of ingredients of mixture.

Having a capacity to be solid or soft allows being capable of adapting many different environment. Although the area of using bio plastics is limited with product design nowadays, they have a great potential to create bigger scaled projects. Theoretically, the durability of bioplastics is not enough to use for a façade design or a building element. However, by using some additive materials, the border of lifespan can be shift. The only example of bio plastics, which is used as a building element, is Arboskin pavilion designed and constructed by ITKE (Institute für Tragkonstruktionen und Konstruktives Entwerfen - Institute of Building Structures and Structural Design) from Stuttgart University. Arboskin (figure 5.1) is consisting of bioplastics containing over 90 percent renewable materials (Dezeen Magazine, 2013). "Thermoformable sheets of bioplastics will represent a resource-efficient alternative [to oil-based plastics, glass, or metal] in the future, as they combine the high malleability and recyclability of plastics with the environmental benefits of materials consisting primarily of renewable resources," explained by project team (Dezeen Magazine, 2013).

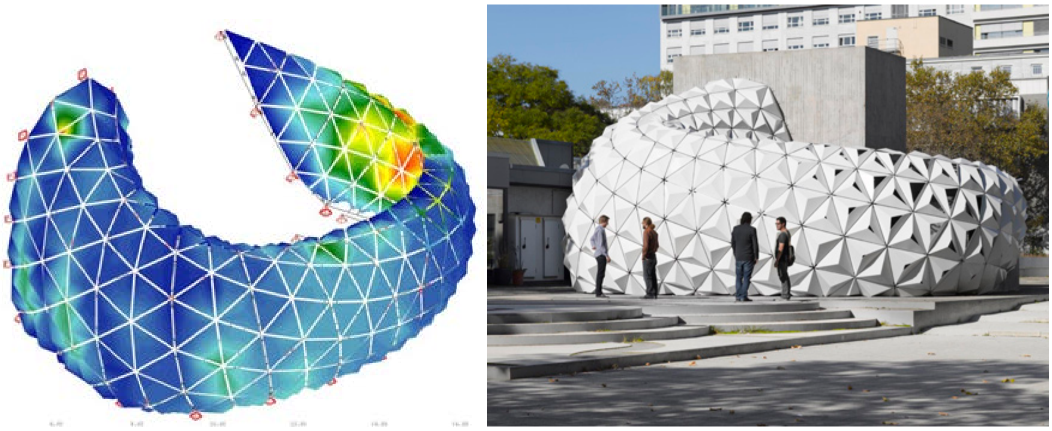


Figure 5.1 : *Arboskin, a façade daily sun position test diagram and projects mock up, constituted of bioplastics by ITKE.*[14]

Although bioplastics have great potential, the design, *Arboskin*, is not an dynamic product. Because of being an ongoing research, ITKE students and supervisors designed the façade to explore the structural durability and endurance of material.

[14] Url - 12: http://www.dezeen.com/2013/11/09/arboskin-spiky-pavilion-with-facademade-from-bioplastics-by-itke/, 60.04.2014

As it is seen in the *Arboskin* example, the strength and durability of the material can be increased with some additions while constituted of 90 percent of biodegradable materials.

The desired behavior of the façade system, which is going to be explained in this chapter, is to be flexible and solid. The aim is to provide these specifications with one material that is used with different densities to cover its own deficiencies. To gain bioplastics with different densities, physical experiments are made by the author.

5.1.2 Bio plastic mixtures: experiments

Basic ingredients of bio plastics are, starch, water, glycerin, and vinegar. The additional materials that are used to produce bio plastics are depend to the result that wanted to be gained. The proportions of constituents define the physical properties of plastic. Different recipes, proportions are tested by the author to draw a frame to potential of material. More starch leads the plastic to be solid, hard, and fragile. Amount of the starch also defines the durability of mixture. More glycerin leads to be more elastic and soft. For flexible results, more glycerin should be added to mixture. Vinegar helps the starch to dissolve easily, and it get into a chemical reaction with glycerin. Vinegar allows the mixture to decompose more. Water makes the starch to melt and creates a homogeneous mixture; however, more water causes the result object to shrink when it dries.

Drying process of the material can be classified into two. Natural drying phase and Drying by augmented force, which is possible with drying machines or ovens. Period of drying changes according to:

- Amount of water that is used

- Shape of the final product

- The physical environment that the output is left to dry.

Drying phase is one of the main issues that give the final product its identity.

	corn / potato starch	glycerine	vinegar	water	soap	gelatine powder	baby oil
semi-solid	●●●●●	●	●	●●●●●			
soft	●●●	●●●	●●●	●●●			
sticky	●	●●●	●●●	●●●			
sticky	●●●	●●●●●	●●●●●	●●●			
fading bubble potential 01	●●●●●	●	●	●●●●●	●●		
fading bubble potential 05	●●●●●	●	●	●●●●●	●●●●●		
solid	●●●●●	●	●	●●●●●		●●	
solid ++	●●●●●	●	●	●●●●●		●●●●●	
solid +	●●●	●●	●●	●●●●		●●●	
~~did not work~~	~~●●●~~		~~●●●●●~~	~~●●●●●~~			~~●●●●●~~
~~did not work~~	~~●●●~~		~~●●~~	~~●●●●●~~			~~●●~~
lasting bubble potential	●●●●●	●●	●●	●●●●●	●●	●●	

Table 5.1: Bio plastics mixtures results chart (By the Author)

As it is shown in the table 5.1, bioplastics can be created according to the desired performance. Table 5.1 shows the amounts of the constituents of bioplastic mixtures and the final performance of mixture. Adherence of these different densities is high, if they are left to dry together, otherwise the materials need an extra layer for adhesion. More glycerin is a way to provide elastic material, which is more flexible than the solid one, but does not have any load bearing specification. It can be inflated or deflated. In addition, on every condition it changes its transmission level.

Additional materials are also used to enhance the specifications of the final mixture. The additions that are used are; food coloring to observe the difference between different sized thicknesses parts. Food coloring does not affect the final products performance because of being used in very small amounts. Granulated gelatin provides strength for membranous surfaces and creates a self-structure for small amounts of plastic. Gelatin is a way of giving strength and durability to final product.

Soap makes bubbles from the hot and liquid mixture. In physical experiments bubbles from soap added mixture is gained by using self-made compressor by the author. However, the liquid mixture is hot while being froth up, the bubbles that emerged are not long lasting. They explode in 2-5 minutes after started to dry and cool. Granulated gelatin is a solution to give durability to bubbles as well. Adding both liquid soap and granulated gelatin into the mixture allows generating bubbles via compressor and giving strength and durability to bubble colony. To distinguish different densities of material, which are used to create bubbles, can be added food coloring.

Using different materials then basic ingredients are also tried. For example, baby oil is used instead of glycerin and the result was a very fragile and solid output, which cannot be shaped inherently or manually.

Sustainability level of bioplastics can be set, however on current position 100 percent sustainability cannot being used for large scaled elements, such as the façade proposal in this thesis. To gain the strength and expand the durability, while providing insulation to water, heat etc. the organic additions in mixture decreases to around 90 percent. Some chemicals have to be used, which are not also harmful for the environment, but helps to expand the durability of material.

The experiments of bioplastics helped to collect a data about the material. A database about bioplastics and combinations is created during the experiment phase by recording the period with photographs, videos and notes.

5.1.3 Material database: physical models and material behaviors

Exploring the bioplastics phase of the thesis contains 47 controlled experiments made by the author. Every single experiment takes about 2 weeks to take the final form. The period can be increase or decrease depending to the thickness of the material, humidity of space that the material is left to dry. Drying the material by force such as oven creates more solid and fragile outputs, therefore this method is not used for all experiments. In this thesis, products of all experiments are left by the author to dry naturally. Naturally drying leads the material to show its basic properties without any addition against heat changes.

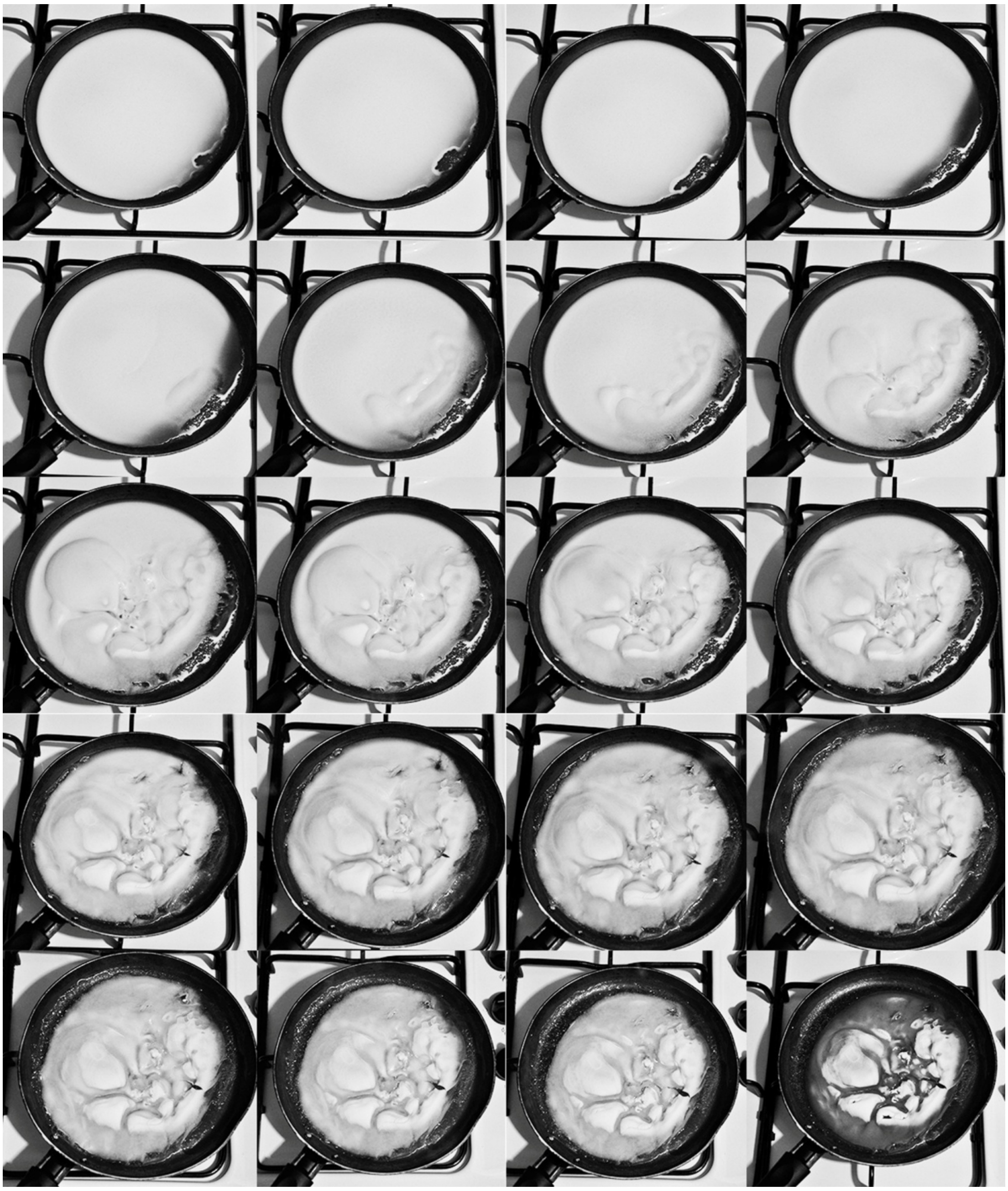


Figure 5.2 : The motion of boiling phase without any stirring of the bioplastics mixture. (By the Author)

Fig. 5.2 is a motion image that shows the boiling process of the mixture. Significance of this process is, mixture is stirred before burning period and homogeneous mixture is put on to cooker. Boiling created peak points, of which densities are very high compared to lower parts. Because, on the boiling phase the homogeneous mixture started to be heterogeneous and starch started to go to the peak points. Other parts of the mixture stayed homogeneous. Over-boiled mixtures are more fragile compared to under-boiled mixtures. Over boiled mixture has a hard body, while the under boiled mixture has a soft one.

Figure 5.3 : Drying phase of the unstirred mixture. (By the Author)

Drying of this unstirred mixture took 2 weeks to take the final situation. As it can be seen from the fig. 5.3, the whole, started to dry and crack from the weak points. The image below, figure 5.4, shows the power distribution of the mixture. As a result, less glycerin leads the product to crack and be solid after drying, more glycerin leads heterogeneous view because of being unstirred but after drying the product did not cracked, however it has some semi-solid parts and soft parts.

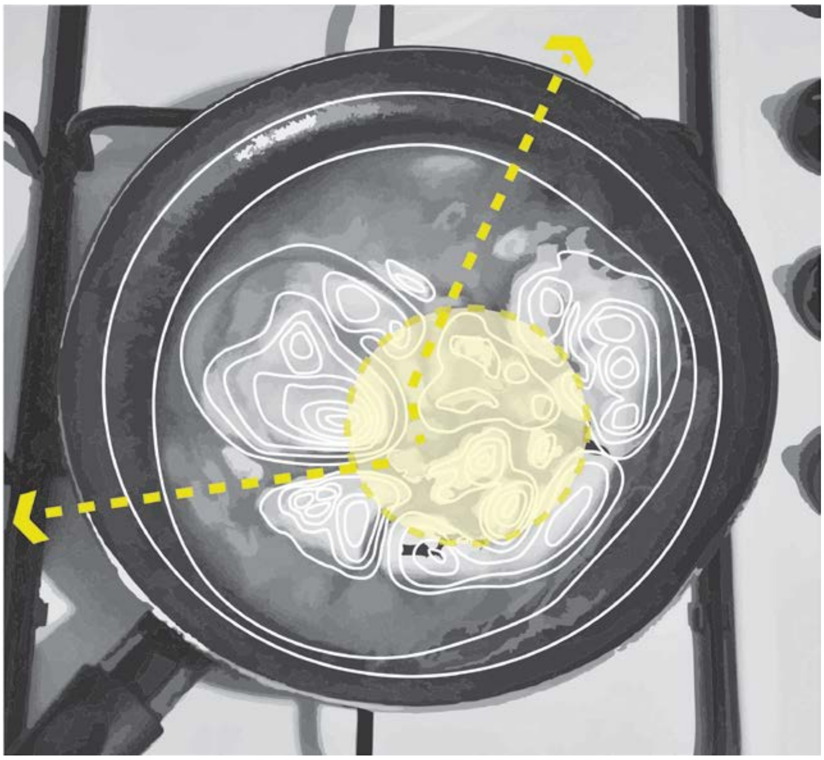


Figure 5.4 : Power distribution visualisation of unstirred mixture. (By the Author)

5.1.4 Material experiments

Bioplastic tests are made by the author to observe the potential of material and shape that the natural process gave to the material and changing of it. Out of experiments based on proportion of ingredients, form based experiments are also made by the author. To test the potential of material itself and combination with other materials, an experiment systematic is set. It is important to observe the behavior with self-combinations and combinations with different materials of the material. Creating a combination of bioplastic to bioplastic or bioplastic to another material changes the general behavior and identity. Systematic of the experiments are based on using natural sources, such as natural drying and mixtures without any artificial protector.

Figure 5.5 shows the elasticity of bioplastic leave that have a high proportion of glycerin. The behavior of the leave is similar with membrane by being elastic.

Figure 5.5 : Expansion test of a thin bioplastics leave. (By the Author)

Bioplatics' behaviors changes according to its thickness as well. Thin leaves and thick materials have different way of response. Thin leaves are more adjustable, transparent, and flexible. On drying period, thin layer do not use their shape. The shrinking level of thin leaves is very low, compared to thick material. As it can be seen from the fig. 5.6, after drying, thick material starts to change its form and it turns into a solid or semi-solid product while the thin leaves around it are still soft and flexible. Those thin leaves take the shape, which is directed by the solid part. For these examples, solid part is working as a structural system that gives the shape to the skin, which is the soft part of the material.

Figure 5.6 : A thick material with thin layers around it. (By the Author)

There are many ways to create thin leaves from liquid hot mixture. First one is pouring the mixture onto a slab, which is waterproof. Being waterproof for the mould is very important because the mixture has water loses during the drying phase. The other alternative to see the thin leaves and behaviors is to create a bubble colony. Bubbles are consisting of thin leaves of material but when many bubbles comes together they also creates their own structures with their intersection points. Bioplastics are not breathable. Therefore, it is expected that the created bubble mountain keep its current situation. However, because of the bubble colony is created while the liquid mixture is hot, as the bubbles cool, the height of the colony decreases. To make the bubbles of bioplastics durable, soap and granulated gelatin is used. The drying phase of the bubbles also took 10 days. After 10 days even any of the bubbles are exploded by the author, bubbles kept protecting their current situation not only because of they are dry, but also because of the bubble structure, which not allows the impact to reach to other bubbles. Because of bubbles are thin leaves; it is possible to set their transparency by changing the proportions of initial mixture. Figure 5.7 shows the bubbles created by bioplastics. To gain a bubble structure, granulated gelatin is used in mixture and after drying, the bubbles are exploded. Even after explosion, there were no bubbles, the intersections of the bubbles continued to work as a structure.

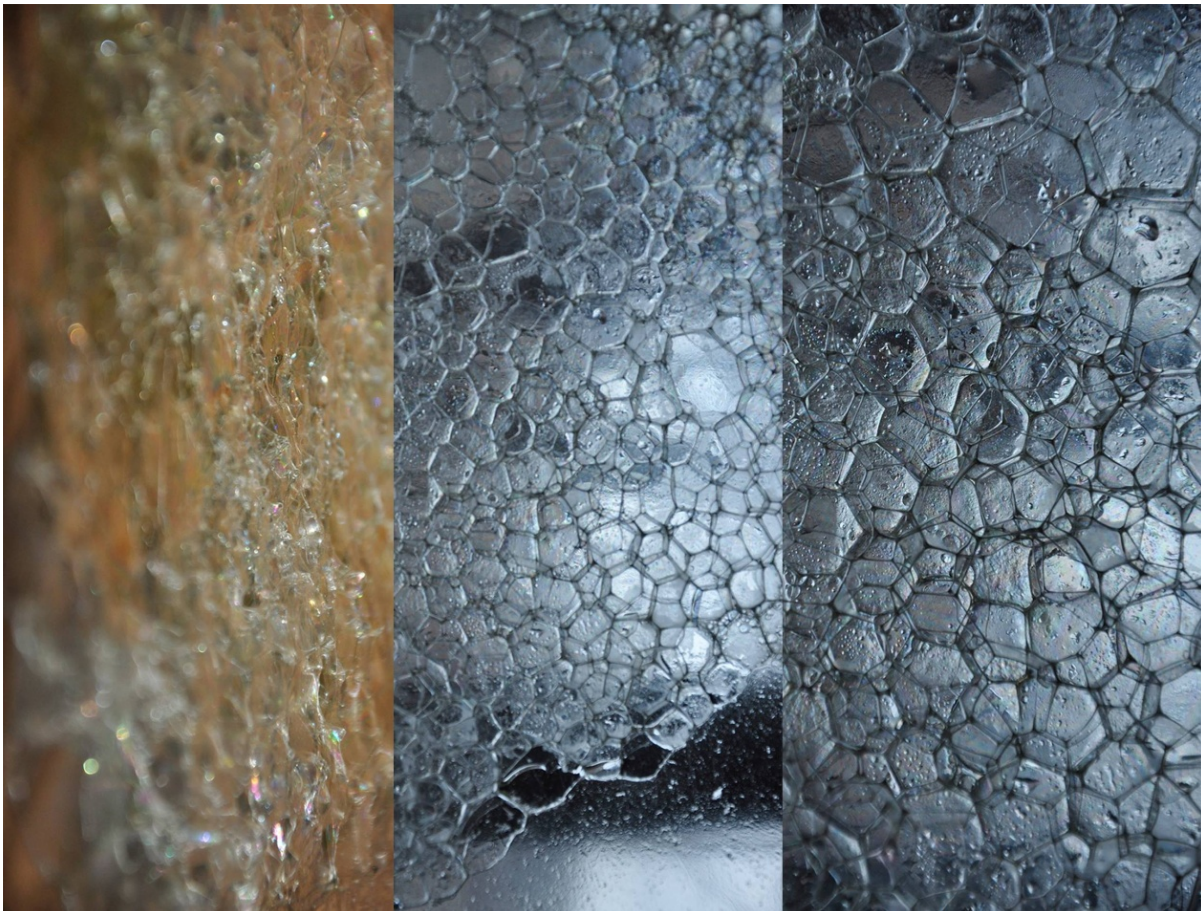


Figure 5.7 : Bubble trials with bioplatics. (By the Author)

While creating bubbles of bioplatics, another test is made which is about bubble stains. To create bubble stain on a thin leaf, granulated gelatin is removed from the initial mixture. A new mixture, without gelatin is boiled and foamed, after the liquid is poured onto a mould. Thus, the mixture does not have gelatin or such a strength addition in it, bubbles are started to explode and their stain, 2D structure is left on the thin leave. This thin leave is more durable than basic and non-stained bioplastics leave. The experiments are shown in the figure 5.8.

Figure 5.8 : Bubble stains on a thin bioplastics leave.

Figure 5.9 : Bioplastic composites consist of different materials to augment the potentials.

Bioplastics composites, consists of different materials, are another part of the experiment phase as it is shown in the figure 5.9. To compare the performances of material to same material and material to different materials combinations allows observing behaviors easily. Comparing the adherence levels and performances with these controlled experiments, helps to create a behavior data, and allows creating variations via computation. Observed behaviors of real life can be integrated to the digital model and computation phase.

These physical experiments resulted in acquiring data about bioplastics' behaviors. Tests revealed information on the necessary proportions of constituents and the way of drying and combining is affecting the final product. Bioplastics with different amounts of starch can serve in different parts of a system due to their capacity to reserve softness, elasticity, solidity and strength. Additions such as soap and/or granulated gelatin make changes on performance in some conditions. An indicator of the performance of bioplastic combinations is sufficiency in completing its own deficiencies.

This behavior database is used to create a proposal for a façade system based on requirements of a façade and potentials of materials.

5.2 A Façade System Proposal

Design phase of the façade system is developed with a heuristic approach to bio plastics. First, controlled experiments are made to observe the potentials and capabilities as described above. Then, combination and performance acceleration is tested via physical and digital models.

The basic properties, which a façade should provide are self-structure, endurance, providing the balance between inside and outside, transmission of light, air, sound on desired amounts and aesthetics.

For the façade proposal, the air in the atmosphere is assumed as the sole trigger and stabilizer.

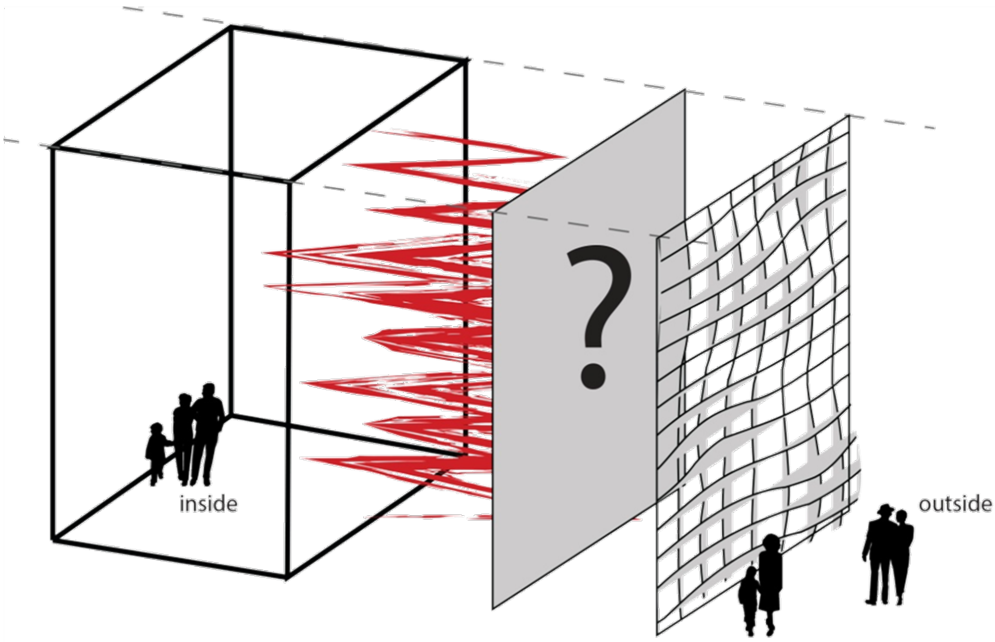


Figure 5.10 : Façade system visualisation, stabilizer between two environments. (By the Author)

Bioplastics are used to create a performative and responsive façade system for this thesis. Different densities of bioplastics are used to provide both structure and skin for the said building element. As it is observed from the physical experiments, more starch and less glycerin leads to gain solid output that can be used as a structural system for the whole. More glycerin and less starch proportions allow having flexible, elastic, and soft material, which can be used as the main skin for the façade. Hence the adhesion level between bioplastics is high; these two materials can be attached to themselves. Bioplastics part that is used as structure is a limiting parameter for the soft skin of bioplastics by limiting the skin to inflate more than it can. Thus, solid part is not elastic; it limits the inflation level of soft body. Figure 5.11 shows the digital experiment of soft skin. The model is generated in the 3D modeling program Rhinoceros and Grasshopper.

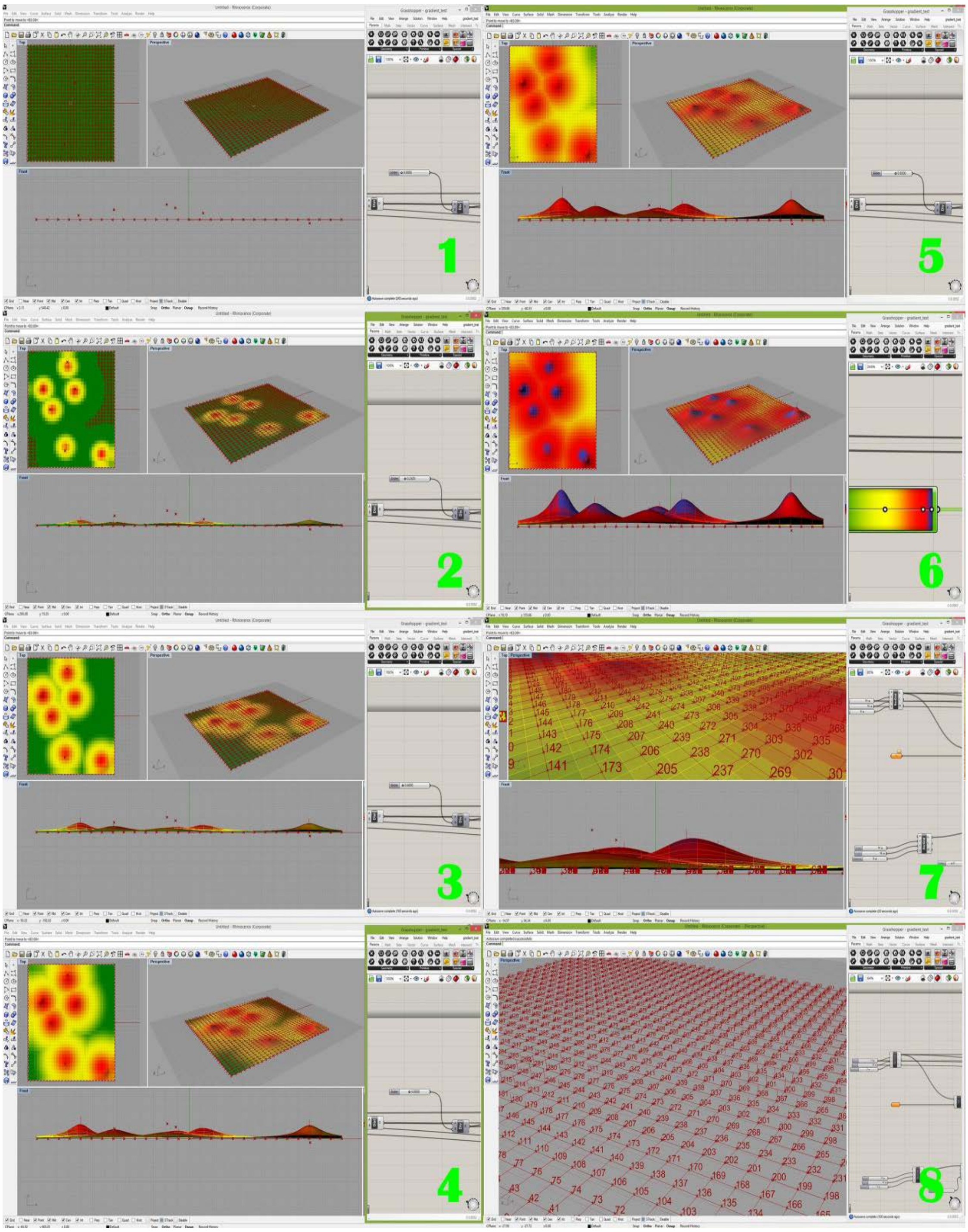


Figure 5.11 : Computational model of soft skin in Rhinoceros, Grasshopper. (By the Author)

First, a set of points are created which can be increased and decreased by number sliders. Number sliders are counters of points that affect the model to simulate the inflation points and peaks of the inflated areas. Then a surface parameter is attached to the system, which creates the skin on the grid. To simulate the inflation, some trigger points are set and their height is linked to a slider that allows the points to change their level of height randomly. After setting the scene, to observe the limits of inflation, a gradient component is added to the definition. The colors are set to behave according to the height of trigger points, which simulates the inflation. As it is seen from the image, green parts refer to safe areas, while the blue peaks refer to points on danger, which is on the limit of rip for the bioplastics leave. With this computation of material, it is possible to create many trigger points and define their relation with one another. To define the points mathematically and to define the coordinates, every point of the base grid, is numbered by another definition. By numbering the grid points, it is easy to calculate the relation of inflations and tp define the positions of laceration areas. The coordinate numbers are shown in figure 5.11, image numbered 8.

The Grasshopper definition (ghx) that simulates the inflation phase of soft bioplastics skin is also a parameter to define the inflation points for the system. If the system consisted of only a single bioplastics pillow, then there would be no need to set trigger points to simulate the inflation. Thus, the façade system proposal is consists of a bioplastics composite which has both soft and solid bioplastics, the skin does not behaves as a single flexible pillow. A limit generator, the structure of the system directs the skin to create many inflation points. As the points, become closer to each other, the laceration possibility increases, due to the pressure of the area.

Façade predicts a system that consists of soft body and solid body, which are refer to structure part and responsive, interactive part of the façade. By using one single material, bio plastics; combinations of a single material with different densities or different proportions of ingredients, have been generated. While the solid system is giving strength to the façade, soft skin is responding to environmental conditions and/or people, users. In the proposal, a semi-permeable skin is predicted due to the potentials of bioplastics, which observed with controlled physical experiments.

In the system, to provide the multidisciplinary, a mechanical system is used to gain pneumatic pillows. Depending on the using density and/or position of the sun, pillows can be inflated or deflated to provide visual connection with outside and to benefit from sun. When the pillows are deflated, this can be manually by using heat differences or mechanically, the density and thickness of the material increases and the transparency decreases, which leads to cut visual connection.

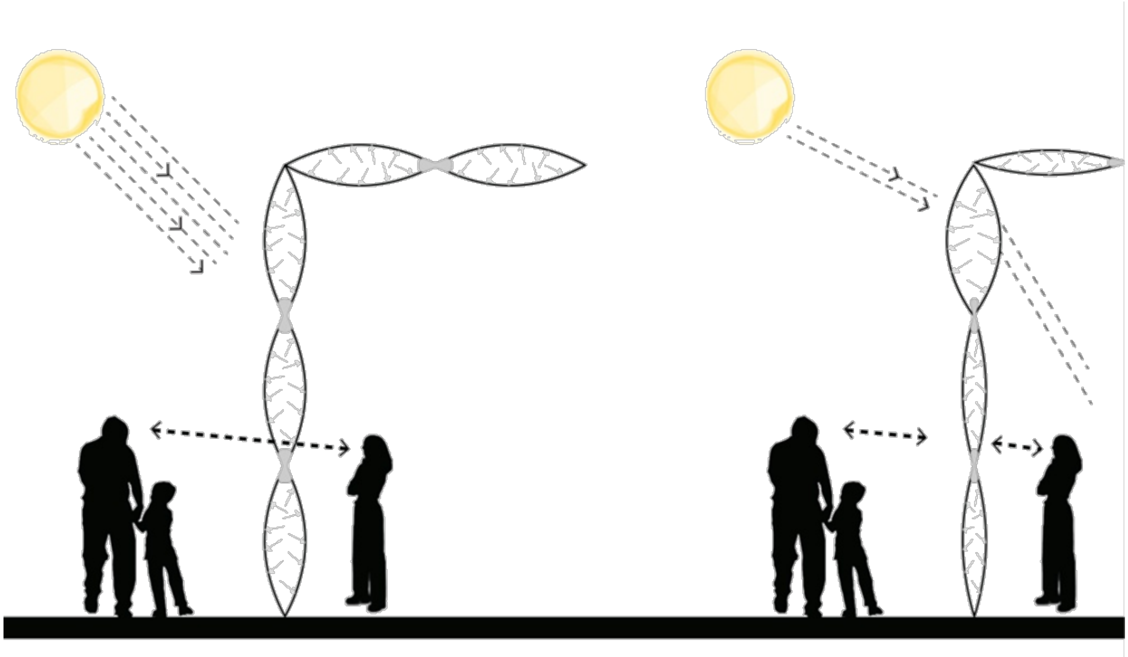


Figure 5.12 : Diagram of façade proposal. (By the Author)

The inflation and deflation also provides heat insulation due to creating an extra layer between two environments. The composite of soft and solid bioplastics can be used as both a façade and a roof. The difference between transparency, permeability and heat insulation level, allows using every floor of a multi-storey building for different objectives. Due to being a soft material, this combination of bioplastics composites prevents the sound propagation.

The solid part of the project is computed and modeled separated from the soft part. Computation of the solid part aims at a structure for the soft body while creating a limit. Limit for inflation provided by the solid body is aimed to decrease the possibility of laceration. The soft and solid bodies are going to work together to cover the building under defined parameters. The parameters for this project are providing an insulation layer, user defined permeability of light, endurance, adaptation to different shaped buildings and high amount of adjustability. Parameters are expected to be provided by the combination and collaborative work of soft and solid part.

In this model of solid part, created by Rhinoceros and Grasshopper, first a net of points is set, which are the central points of each cell. After defining central points; a shape, which can be amorphous or rectangular, is defined for every single point to fill the net to create the structure. Sliders are added to change and set the depth, position, and radius of each cell to see the shape possibilities of solid body. As the value of depth is increased by using a slider, dominant components shape the whole. To gain a random solid part, which provides the soft skin to have a more independent space, different patterns are tried via computation. By using images, such as a dot pattern or a density graph, the density of cells and the positions are set to gain different structure systems. This specification is added to the model to explore, what if the solid part moves, with the helping of mechanical systems, according to the inherent, or environmentally forced motion of soft part. As a result, designs that are more dynamic can be gained, which also provides multi-functionality to the inner space by generating big cells to provide visually communicated environments, or small cells to decrease the visual contact.

Figures 5.13 and 5.14 are the snapshots of computation phase of the solid system proposal. As it can be seen in images each of which consist of 10 different phases of experiment, the dynamism can be observed and seen with the helping of number sliders that changes the values that are defined according the physical experiments and material potentials.

Combination of solid and soft parts creates a composite that can be arranged according to desired forms as an initial step. After start using the system, it starts to create its own form by using its inherent behaviors as a response to users and environment. A multidisciplinary study should be followed to achieve to design a performance based and interacted façade system.

The proposal that is computed in the scope of this thesis depends on both inherent behaviors and mechanical systems. Hence it is possible to create variations within defined material capabilities and limits, new designs and working systems can be designed. Although Rhinoceros with Grasshopper add-on is used for this thesis, there are many computation tools to test the real world potentials of a system: Material.

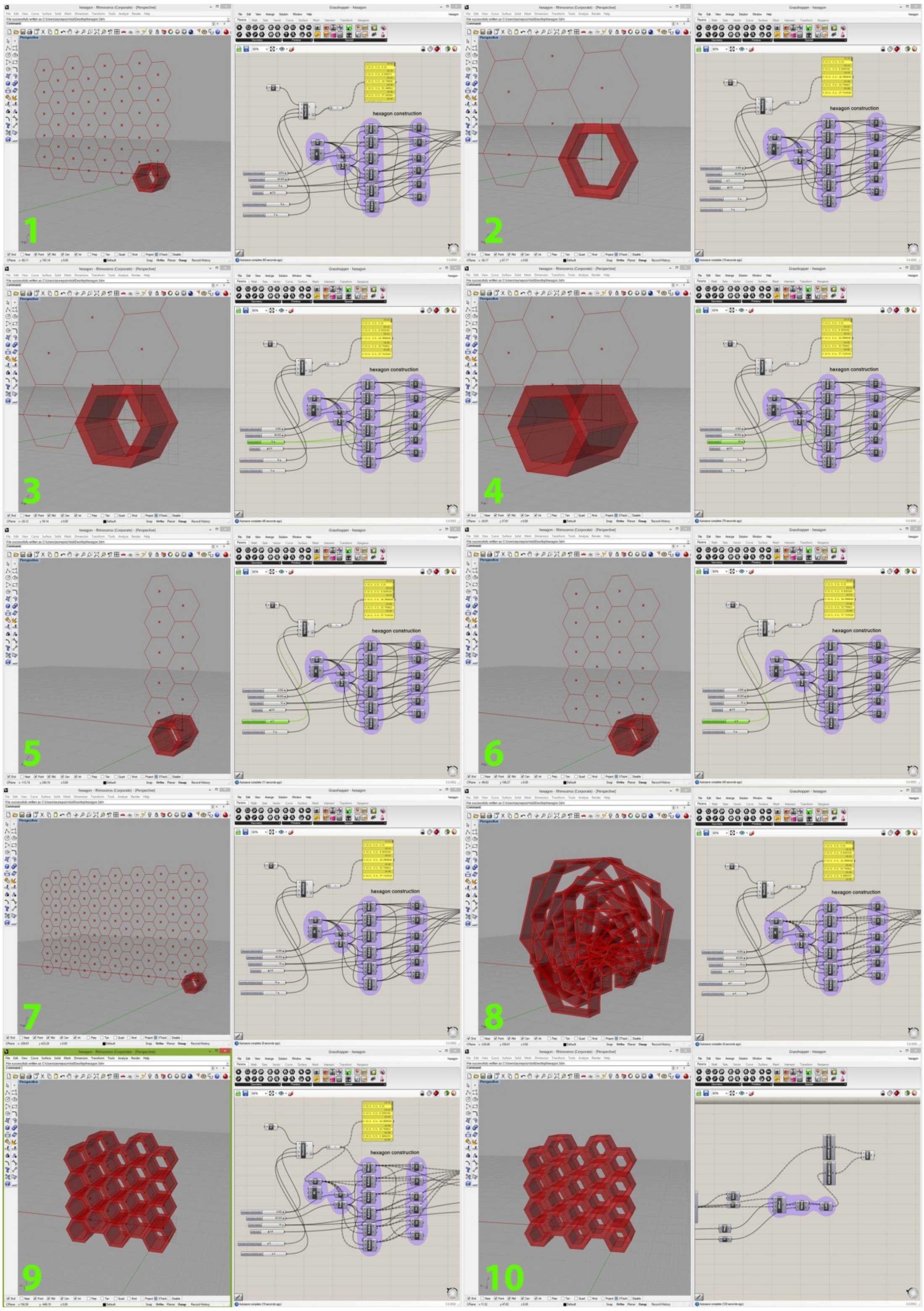


Figure 5.13 : Snapshots of computational model of solid system-1

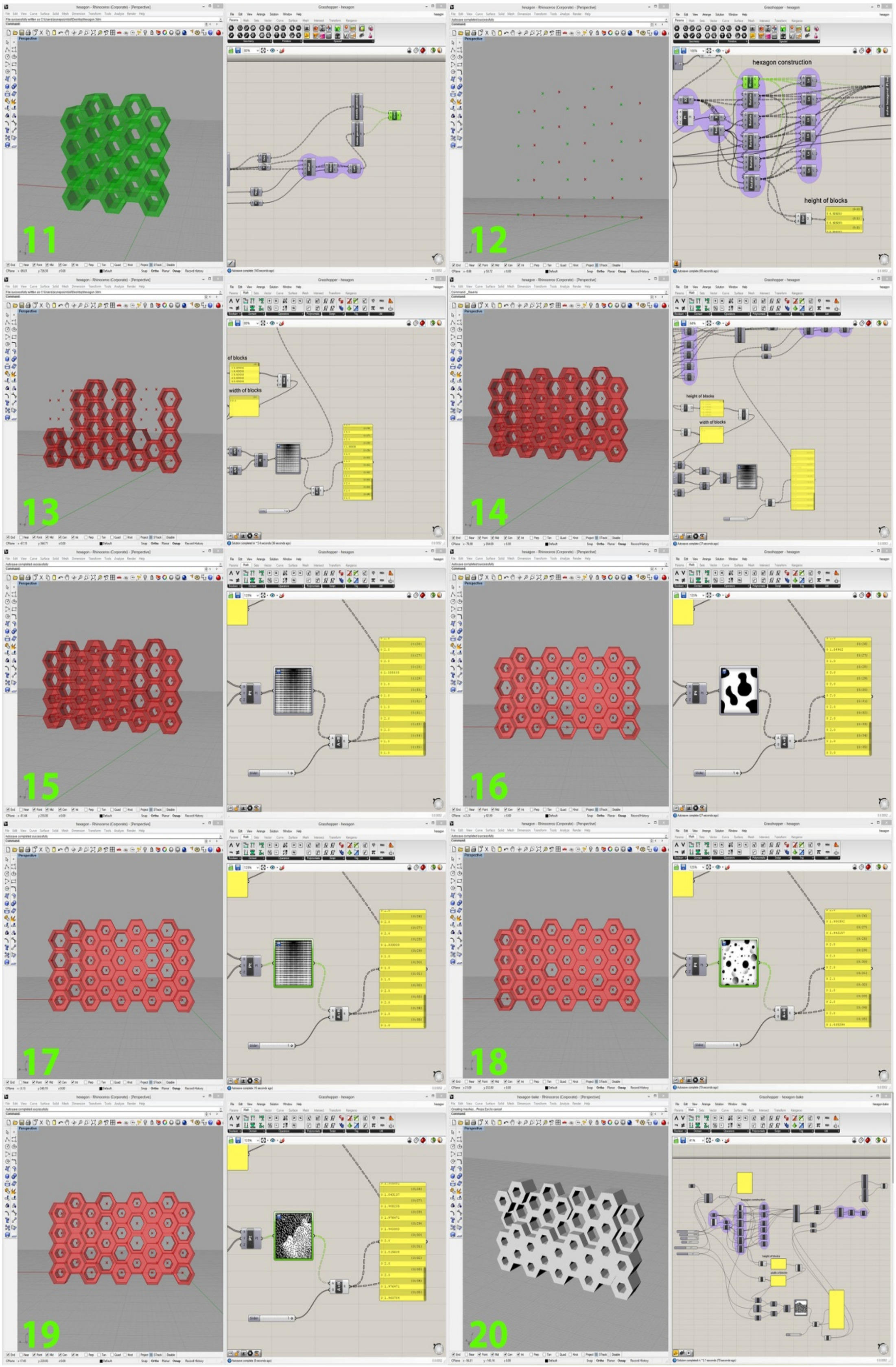


Figure 5.14 : Snapshots of computational model of solid system-2

Digital experiments shown in this part are trials to simulate a façade system that is designed according to the physical properties of a bioplastic material. As a result, a façade system is designed to consist of one material for both structure and cover. The working principle of the façade is inflation of the soft bioplastic part according to necessities of users to provide parameters such as visual connection and insulation, while being structured by the bioplastic solid part. The project is modeled both physically and digitally to gain emergent forms and possibilities by creating iterations.

To increase the variations and show the possibility to simulate behaviors via computation, the author made different digital experiments as it is explained in the next part.

5.2.1 Digital design of the material

Physical and digital experiments, done by the author, are intersected to increase the variations. The performance limits and specifications that are observed from the physical experiments are reunited in computational model.

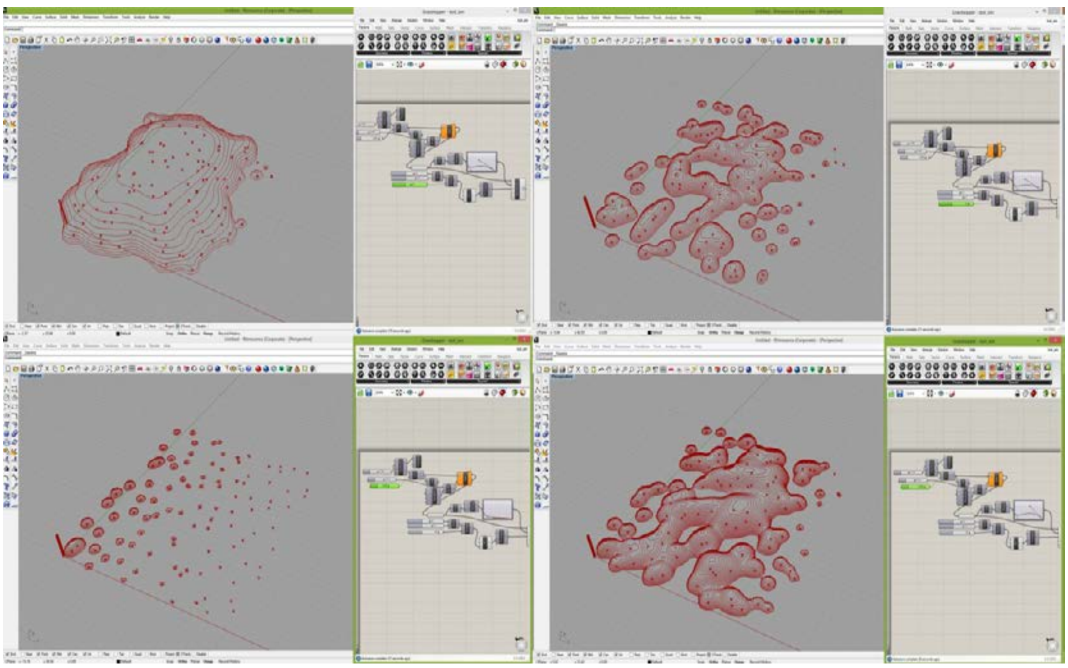


Figure 5.15 : Boiling computation of bioplastics mixture. (By the Author)

Figure 5.15 is the output of computation phase for the example figures 5.2 and 5.3. The boiling phase of bioplastics are observed and recorded via digital camera. The recorded video is uploaded to computer and borders and heights of boiling phase is defined on Adobe Illustrator. After calculations the Rhinoceros, Grasshopper definition, which belongs to Tuğrul Yazar (designcoding, 2012) is modified to simulate the boiling phase of mixture. As it can be seen from the fig. 5.15, contour lines for the height is defined and random points are set for being the triggers. As the value of inflation, boiling increases, the contour lines increases too. After simulating the current and real behavior of the boiling mixture, computation is continued by the author to create iterations. By setting the positions of trigger points, which are related with the heating level and temperature in real life, bigger peak points are gained. However, when the heating phase is done by separated flames that do not have high temperature, it leads the mixture to boil and create lower peak points from different trigger points, as it is shown digitally in Fig. 5.15.

State of the computation on researching an interactive system has a great percentage of the whole. Thus, it is very difficult to observe every single behavior and response of materials one by one physically; computation allows creating much iteration under parameters, which are defined by practiced physical experiments.

5.2.2 Computation

Unlike basic 3D modeling, computation allows to extract information from model to real world. Softwares are being developed by firms, engineers and architects to recompense the necessities of dynamic and changing computation world. Building Information Modeling (BIM) is one of the computation techniques, which is directly related with physical environment conditions and material specifications. There are many programs, which allow making information based 3D models to augment the influence area of model from a visualisation tool to a construction and performance calculator. Revit and Vasari plug in, Rhinoceros and real world add-ons of it, Autodesk AutoCAD Ecotect are example of programs that are created to model architectural drawings in a relation with environment, material and physic rules.

The thesis study uses computation as a result of physical models which are based on material performances and capabilities. The process of computation tests material performances with environmental conditions and forces to simulate the behavior. An emergent potential is also gained by using not only defined materials, potentials and forms, but also by using composites and testing inherent behaviors too.

Computation is used in this thesis to give shape to the physical performances. The elasticity of bioplastics is computed and simulated as inflated pillows whereas the solidity of starchier bioplastics is computed to shape the structural system of the façade. By the combination of soft part and solid part a façade is gained from one single material.

5.3 Final System Review

The project questions the emergent potentials of materials and the possibility of using the emergence of materials as an advantage on building scale. Using of materials is a major parameter on design performance.

Physical experiments revealed the behaviors of bioplastics under defined parameters such as different proportions of mixture, the way of boiling and drying, combinations with other materials, combinations with itself. Bioplastics can be elastic or solid depending on the proportions of mixture.

Digital experiments, which are modeled in Rhinoceros and Grasshopper, are used as a way of simulating the real behaviors and to create combinations of different potentials to measure new potentials. Soft and solid bioplastic mixtures are combined to create a façade system.

Material behaviors are tested not only physically but also digital and as a result digital combinations are gained. Emergent forms not only becomes with physical experiments, but also they can be generated via computation by defining material properties and influence area. Digital experiments are not enough to achieve emergent results which are the simulation of real behaviors. To achieve emergent forms, which can also be done by physical experiments, first, the properties of material should be questioned and the borders of material should be drawn. This is possible with physical experiments.

Response borders of materials should not be accepted as an obstruction, which limits the movement capability. Combination of capabilities helps to make a shift in existed borders and allows to achieve emergent forms.

6. CONCLUSIONS

Physical material experiments and material computation are on-going and developing subjects of material world. Still, as conventions directs designers to use well-known and learned forms, materials are shaped according to the element that they are going to be used for. Materials have the potential to rule their environment and create dynamism similar to living organisms by being receptive and responsive. Response provides communication between interacting subjects, which can either be a building element or a person. Communication of living organisms and environmental changes with buildings helps to create user interacted, dynamic spaces. As technological developments leads to a change in natural and artificial environments, dynamism of the naturally emerged, again with a holistic view to materials, which is based on knowledge based thinking and the interest in trials to find solutions from the basics. Although, dynamism of a material and form-changing process of the material is accepted as a disadvantage in the current understanding of the construction field, these situations can be turned into an advantage by using inherent behaviors of materials.

There have been much research and many experiments on material possibilities since using materials as a performance object instead of a tool for physical appearance of defined form. Strategies for the use of materials and form have evolved with the development of technology. Since physics, technology, material sciences, design, ecology and other scientific branches are related with materialisation, a holistic and multidisciplinary approach should be adopted for realistic, dynamic and sustainable design. Composites are the designed and well-thought products of this multidisciplinary organisation by being both performance based and aesthetic inputs, which depends on the location on the building.

Increasing area of using composites and inherent behavior based potentials is going to trigger environment sensitive, ecologic design developments. Materials have the power to create desired performance without any environmental harmful addition.

The additions that only gives the material stability and visual aesthetics, limits the responsive design at the same time. To create more examples on daily life, not only on exhibitions or on pavilions, materials should be used widespread according to their inherent performances and capabilities. With true combinations and choices, responsive composites can be generated and multi-functional, reusable, dynamic spaces can be designed.

This thesis aimed to design a building element, façade, which based on materials' inherent behaviors and response capabilities. Façade is the skin of the building, facing with both environment and inside. Thus, it is an interface between two environments; the properties should be different from other elements such as load bearing system or floors while being in a relation with all those systems. A façade has relation with all elements of the building including the environment it is in and the users that are in and around it. The material of the façade should cover the expectations such as being a resistant to environmental forces, having an aesthetical aspect etc.

Bioplastics are observed and tested to draw a borderline of the material possibilities. The author has firstly conducted physical experiments. Physical experiments are based on observing the basic properties of material and combination possibilities with itself and other materials. To prepare bioplastics, different materials such as liquid soap, granulated gelatin, food color are used in addition to basic constituents of bioplastics. Bioplastics are made of water, starch, glycerin, and vinegar. Different proportions of constituents causes different bioplastics types such as soft output, fragile output etc.

The physical experiments are devised to observe bioplastics, the potential of creating building elements with such biodegradable materials are questioned and experimented. Is it possible to use them for big scales via combinations or not? The composite, bioplastics, is started to used as a building material in the technologically developed studies. Combinations of different properties allows the material to be more strong and convenient for a building element.

Physical experiments have taken nearly 40 days to complete, including drying. Drying of the material takes a long time depending on the environment that the product is left to dry. Drying causes some deformations and changes on output, therefore every phase of experiments is documented via photos, videos, and notes. Physical experiments are the initial point for the thesis to define the physical properties and behaviors of the bioplatics. Experiments provide information about bioplastics to use in the digital experiments.

After defining physical possibilities such as elasticity, strength, and limits of bioplastics, a digital model is created by the author to create iterations of design proposals. Different densities of one material, bioplastics are used to create the façade and computation is made according to the extracted data of bioplastics from physical experiments. Different densities of bioplastics cause different behaviors as it is observed from the physical experiments. Gaining fragile product or elastic product is directly related with proportions of constituents in bioplastics mixture.

Digital model, which is created by the author on the 3D modeling program Rhinoceros and Grasshopper add-on, is a performance test to simulate the behaviors of bioplastics. By using the collected data of limits of the bioplastics, digital model helps to visualize the spectrum that a bioplastic mixture can perform.

Material potentials are becoming a widespread area in experimental world of both architecture and engineering. Although being an intersection area, the potentials are observed and developed separately by engineers and architects because of the lack of communication for construction area. The experiments of potentials should be made in a collaborative work not only by researchers, but also by designers and engineers.

This thesis collects knowledge on material potentials based on inherent behaviors and response capabilities for dynamic and responsive designs.

The design of a façade explores the potentials of using CAD tools to generate a system that relies on results of physical experiments. The study also presents, in bioplastics a composite that consists of one material but with different densities. It is possible to increase the potential of a material not only by combining with other materials, but also by combining with itself. Creating a combination of composites, which has the same constituents but with different proportions, allows for a system that covers its deficiencies by itself. Combination of bioplastics in this study has resulted in a system that is covered and structured by one single material. Digital process is used to increase the combinations and to visualize the physical possibilities.

The study can be continued by making experiments with different materials and combinations of bioplastics with different materials. Future line of the project is, using materials' behaviors for not only visible elements that have an aesthetic concern, but also every element of the building, which are performance based systems. Combining the behaviors with systems allows reaching more flexible and reusable spaces. As the technology and computation tools develop, the future lines of the project will be branched out. Thus, material studies and computation is an on-going subject, new experiments is going to be evolved parallel with technological developments. The aim is based on changing the point of view to materials, and encourages rethinking the using strategies.

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