Design research and applications of contemporary digital technologies in the fashion industry

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January 2020
Thessaloniki - Greece

Abstract

This dissertation lays out an approach in fashion design process informed by innovations emerging from computational design and 3d printing technologies, it investigates how new digital technologies are explored by designers, in order to realize groundbreaking products tailored for the body.

With computational design as a driver, new sets of digital design tools are introduced, designer assumes the role of coder and end user actively engages with the design process. Furthermore, an extended research expands upon all product categories inside a fashion design portfolio, by investigating various levels of integration between computational fashion design workflows and 3d printing processes; highlights the underlying role of computer generated geometries, mass-costumization and behavioural materials, as prerequisites in order to realize products perfectly tailored for the body. This research results in creating an indicative diagram that can be used as a guideline for fashion design.

Furthermore, this dissertation aims not only at describing a set of guidelines for fashion but also explore current limitations, possible workarounds and realize meaningful collaborations as a result. The outcome of that exploration as well as the diagram should be able to explain;

“How 3d printing integrates with computational fashion design and how it fosters innovation in fashion industry as a whole.”

Keywords: computational design,3d printing, computer generated
geometries, mass customization, behavioural materials

Nikolaos Papanotas
January 2020

Preface

I would like to express my gratefulness to my supervisor Dr. Ioanna Symeonidou for her valuable guidance towards the completion of this dissertation. I would also like to thank my family and friends for all their support upon completion.

Contents

1/ Introduction

/1.1/ AIM & SCOPE

The purpose of this dissertation lies in an era of fashion design likely influenced by integrated computational design workflows and efficient 3d printing processes, in order to realize a new potential.

During early stages of exploration, a new important perspective emerged; the idea that fashion design is influenced by revolutionary computational workflows that describe the logic behind design proposal rather the form itself. An extended research based on novel paradigms in fashion design, expands on computational design and its various forms of expression, reveal a paradigm shift towards iterative fashion design, characterized by user costumization, non-linear form generation and non-euclidean geometries, while at the same time, studies on projects reveal efficient 3d printing processes in the form of products such as wearables and jewellery.

With those factors as a given, research covers 3d printing limitations and expands in a wider fashion design portfolio, where sensibilities in production result in far more complexity in order to realize products, such as footwear and apparel design. These sensibilities have to do with comfort, perfect fit and flexibility in bodily movement. As a result, research explores projects where production is characterized by workaround solutions found in traditional manufacturing as well as at the geometry level with simulation, sophisticated folding processes and new material fabrication.

At this point a new important perspective emerges as a result of previous outcomes of exploration; the prospect of 3d printing fashion design items in one piece and expressing far more complex properties of the body into its surroundings. Predominant concept is ‘geometry begets materiality’, the ability of ‘geometry’ to manipulate ‘material’ in order to achieve the desired behaviour and express dynamic properties. Projects covered here express far more complex properties of the body, such as emotion, filtration and bad posture correction, thus leading towards the socio-cultural nature of fashion design.

Concequently, research results aims in creating a diagram of successful integrations between computational design workflows and 3d printing technologies, effectively answering the question;

“In what ways does 3d printing processes integrate with computational fashion design and how does this foster innovation in fashion design, while addresing key sensibilities of this particular creative field?”

/1.2/ RESEARCH QUESTIONS AND OBJECTIVE

There is one main question prevalent throughout the entire dissertation that keeps the subject seamless and is essential to understand the logic behind the process;

“In what ways 3d printing processes integrate with computational fashion design and how this fosters innovation in fashion, while addressing key sensibilities of this particular creative field”

Furthermore research objectives are pursued, in order to keep order and assist into developing a structure throughout the research. All those questions were used to develop chapter and topics, assisting research completion. These are;

<u>Chapter 2; Computational Fashion Design: designer {coder} and mass costumization</u>

Q1. What is computational design, how does it influence fashion design process and how does it affect roles, disciplines and products? What does this mean for the user?

Q2. How are 3d printing technologies incorporated inside a Computational design workflow? Nowadays, to what extent are 3d priting processes efficient?

<u>Chapter 3; Computational Fashion Design & 3d Printing: integration in a wider fashion portfolio</u>

Q3. Are there any key sensibilities, limitations and byproducts when integrating computational fashion design workflows with efficient 3d printing production?

Q4.How do 3d printing technologies perform in a wider Fashion design portfolio?

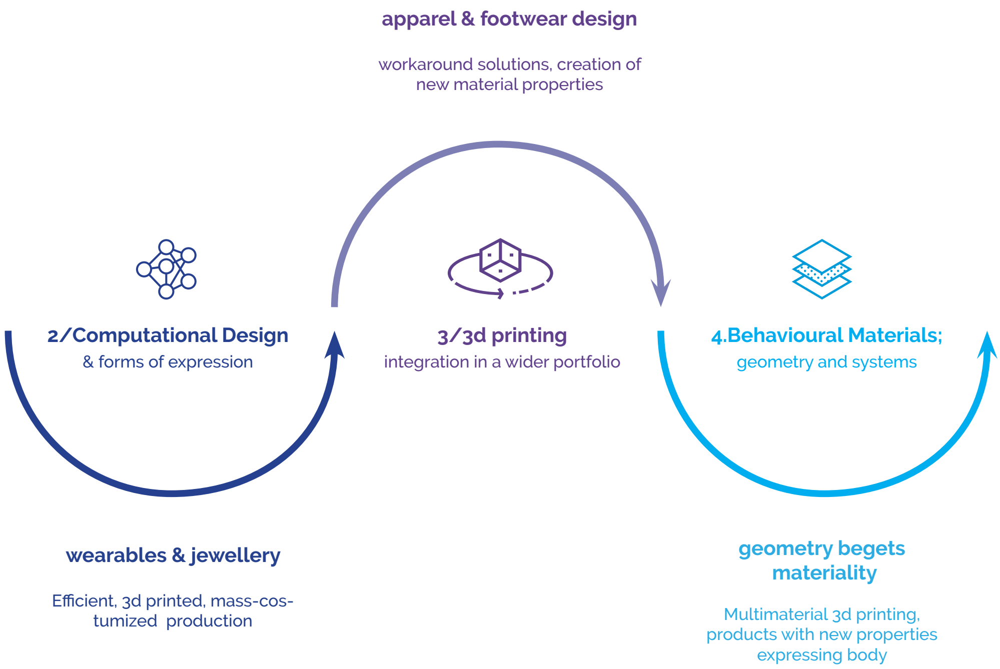
Chapter 4: 3d Printing & advanced, behavioural materials for the body

Q5. How do various levels of integration, between Computational Design and 3d printing, influence material behaviour? How does this translate back to fashion design?

Conclusions: Common themes behind all projects and diagram of guidelines as reference

/1.3/ METHODOLOGY

There are two directions clear as to how to approach the subject effetively. First one is a process driven approach, influenced by major subjects like Computational Design, 3d printing and Materials, prevalent throughout investigation process, from material collection to source examination, Second one is a paradigm driven approach, directly influenced by key projects. Both directions compliment each other, assisting in creating research content.



/1.4/ LIST OF REFERENCES

During the research undertaken in the field of digital technologies in the fashion industry, it was seen that there is very limited bibliography available. Therefore to cover this bibliographical gap, the research has also drawn valuable information from internet sources of different types, such as the websites of the respective designers, fashion editorials, videos, blogs, interviews and online fashion portfolios or commercial websites. All the references and sources that have been used can be found at the List of References in the end of this dissertation. The research was based on the study of exemplary projects and the analysis of the corresponding digital technologies.

2/ Computational Fashion Design: designer {coder} and mass costumization

/2.1/ Form generation: a paradigm shift in Fashion design

Generating form is one of the profound questions in fashion design field and education. Fashion design process is frenquently accompanied by a series of discussions that question the legitimacy of an approach in terms of its aesthetics, form and function, culture and trends, material performance, user needs and feasibility costs, in as many configurations as humanly possible.

Only until recent years, computational tools have introduced innovative techniques, informing all fields in design and production. These techniques are identified by terms such as “parametric” design, “algorithmic” design and ‘generative’ design. Design proposals are characterized by logic and intent rather than just focusing on the form itself, effectively changing the role of designer as a coder. Furthermore, they offer new design pathways by separating well enstablished relationships between representation and form, in favour of complex computer generated, non-euclidean, geometries, thus enabling mass costumization,

/2.2/ Definitions and applications in Fashion Design

There are aproximately three main categories as of now, while they are indentified by terms such as; “parametric” design, algorithmic” design and ‘generative’ design. Overall they can be described as non-linear design methods where generation of form is based on processes, rules and algorithms, stemming from computational tools such as Processing, Rhinoceros 3d, Grasshopper and other custom scripting platforms,

/2.2.1. Computational Design: an iterative process

According to Wassim Jabi, the emergence of such methods can be traced back to design and its iterative design process, Design is traditionally invested in giving solutions to particularly complex problems that raise new questions, in a short period of time. These new questions often lead to refined or entirely new solutions. Designers were the first to model with computer-aided design software in order to help visualize ideas about form, However the vast majority of models lack the ability of interactive modification. (Jabi, 2013). David Rutten, Mc Neel's lead Grasshopper developer describes this paradigm as "Manual/Cad" design where keyboard and mouse act as input devices, and when designing "Results are recorded. Processes are not." (Rutten,2013)

/2.2.2. Parametric Design and Algorithmic Thinking

In order to address this problem, designers have begun to use specialized software that enable the use of parameters and the ability to specify relationships among them, The great benefit of such an approach is that, by changing only a few parameters, the rest of model can update accordingly and mirror those changes. These changes are managed by the specialized sofware, "while designers set the associative rules". (Jabi, 2013) This process is described as "parametric" design, and in case where the designer creates an algorithm that manages those rules centrally, the process then becomes 'algorithmic' design. (Rutten, 2013).

Jabi foresees a shift in focus in what he terms as "Algorithmic" thinking; "Associative and parametric geometry, in essence, describe the logic and intent of such design proposals rather than just the form of the proposal itself. Engaging these parametric and algorithmic processes requires a fundamental mindset shift from a process of manipulating design representations to that of encoding design intent using systematic logic". He also concludes that parametrically and algorithmically made models represent "the internal construction logic of the structure" and also mimic real life counterparts "subject not only to user changes of geometric parameters but also to structural forces, material behaviour and thermal and lighting variations" and can be digitally fabricated. (Jabi, 2013) Obvious advantages are also outlined by Terzidis, who says "Algorithmic" thinking can help "build consistency, structure, coherence, traceability and intelligence into computerized 3D form". (Terzidis, 2003)

/2.2.2.1. The properties of a Parametric design system

All parametric systems have several characteristics in common; they are "object-oriented" and store in "classes" or "families", can be created by "methods" and enable the expression of "parameters".

Object-orientation

User interacts with "objects" (circles, spheres e.t.c.) and stores them in an object oriented database, for later access, search or modification. Every single object has "attributes" associated with a "value". Hypothetically an object circle will almost always have "attributes" such as "center" and "diameter" and one attribute describing its "name". (Figure 1) A popular way to annotate is using full stop by separating object and its "attributes";

'object.attribute'

Furthermore, if someone wants to mention the radius of an object named CircleB then the following will happen;

"circleB,radius"

"Values" can either be expressed in constants or functions. The use of functions give the power to specify connections with "values" of other "attributes". Hypothetically, the following function describes the "value" of a radius of a circle;

C.Radius = distance(PointA, PointB)

This function means that the "value" of a circle's radius equals the distance between "PointA" and "PointB". As such, the "C.Radius" is a dependent variable, as it depends on the 'value' of the distance between "pointA" and "pointB". That relationship is often called "associative", and the derivative geometry as "associative" geometry. One big advantage comes is when we think about it as a network of associated "values": by modifying known entities one can create new unknown ones, causing a domino effect and changing the characteristics of the final design solution. This is the power of the so called "associative parametric" design system. (Jabi, 2013)

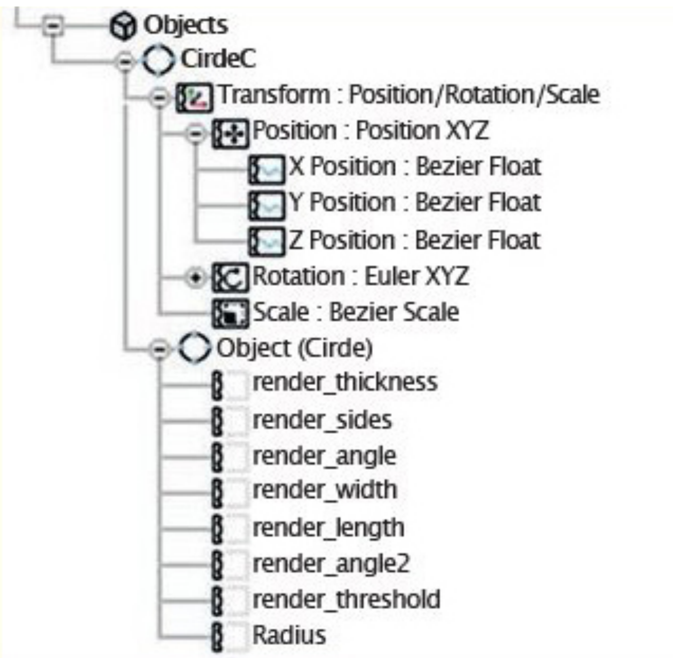


Figure 1_The attributes of Circle, as shown inside Autodesk 3ds max (source; Jabi, W., 2013. *Parametric Design for Architecture.* London: Laurence King Publishing Ltd).

Families and Inheritance

Objects that share common properties can be stored in "family" of objects. The great benefit is that the grouping objects can share attributes with their siblings and at the same time receive attributes from their parents. (Jabi, 2013)

Methods

Methods are functions and algorithms that regulate an object by modifying its "attributes". Jabi gives an example on the role of methods; "In the case of a circle, one such method could be to construct the circle by specifying the position of its center and the value of its radius attribute. Another method could be to specify three points that circumscribe it. The system can simply tell a circle to draw itself" (Jabi, 2013)

Parameters

Core of all parametric systems, the term "parameter" derives from a Greek word for para (beside) + metron (measure). (Etymonline.com., (2019)) Reflecting upon the Greek etymology of term "parameter", one can say it is a term that determines another measure. In the field of mathematics parameter is a

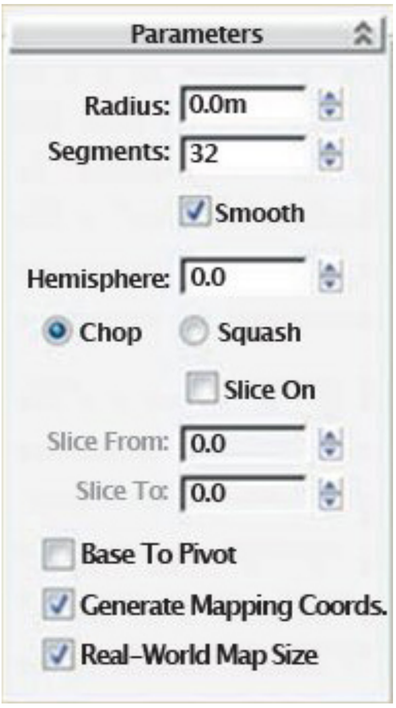


Figure 2_ Parameters and creation methods (sphere) inside Autodesk 3ds max (source; Jabi, W., 2013. Parametric Design for Architecture. London: Laurence King Publishing Ltd).

“Variable term in a function that determines the specific form of the function but not its general nature, as a in $f(x) = ax$, where a determines only the slope of the line described by $f(x)$”.(Dictionary.com., 2019)

As for parametric design software, the term “parameter” stands for a variable term inside functions that specifies the other values and its fundamental characteristic is that it can have a range of possible values, giving the ability to explore many design variations with further user modification. (Jabi, 2013)

/2.2.3. Fundamental Themes in Parametric Fashion Design

The potential of this poweful digital workflow to become dominant in contemporary fashion design practice, can be described by Patrick Schumacher, key figure in Zaha Hadid Architects, a reknowed architectural studio involved in fashion items as well as footwear design. According to him; “We must pursue the parametric design paradigm all the way. Systematic, adaptive variation and continuous differentiation (rather than mere variety) concern all design tasks from urbanism to the level of tectonic detail. This implies total fluidity on all scales”. He also remarks that fundamental themes in parametric design, include terms such as “versioning”, “iteration”, “mass-customization” and “continuous differentiation”. (Schumacher, 2009)

According to Jabi, “versioning” and “iteration”, are terms borrowed from software development field, “mass-customization” is a manufacturing term, whereas “continuous differentiation” is a term borrowed from the field of calculus. He describes them as follows;

Versioning

“Versioning” is a process of creating versions or variations of a design solution that is developed in changing conditions. Parametric software file format is “wired” instead of being static, just like a “string puppet”. This wiring grands the ability to tweak and manipulate a design solution, creating new versions when conditions change. (Jabi, 2013)

Characteristics of “versioning” can be found in fashion design project “Melissa Shoes” by Zaha Hadid Architects, in collaboration with Melissa. The idea behind the design of the pair of shoes is to engage with organic contours of the body, while convey assymetric qualities in order to evoke a sense of continuous tranformation, (Fairs, 2008) In order to achieve assymetry, designers created a distinct version for the left pair,with an extended heel colar (Figure 3), while keeping the overall feet dimentions of the pair the same.(Figure 4)

Figure 3_Melissa Shoes By Zaha Hadid Architects; notice the assymetry between the left and right pair

(source; “Melissa Shoes by Zaha Hadid Architects.” Dezeen, 24 Oct. 2008, www.dezeen.com/2008/10/24/melissa-shoes-by-zaha-hadid-architects/)

Figure 4_Melissa Shoes By Zaha Hadid Architects; overall feet dimentions remain the same (source; “Melissa - Zaha Hadid.” Melissa,https://www.melissa.com.br/uk/collabs/zaha-hadid. Accessed 23 June 2019.

Iteration

‘Iteration’ refers to a cyclical process of repeating a set of steps. In parametric design, the designer sets a range of instructions and iteration can create variation at every repeat by following that same set of instructions. Iteration is a powerful process for optimization and time management purposes in design. (Jabi, 2013)

Characteristics of ‘iteration’ can be found in a collaboration project between Zaha Hadid and United Nude called ‘Nova Shoe’.(Figure 5) Morphologically, the footwear features a 'striated surface resembling geological formations' (Fairs, 2013) Designers have achieved this form by varying the size and shape of those formations, right from the bottom of shoe (sole) and up to its heel colar, following the curvature of the leg. (Figure 6)

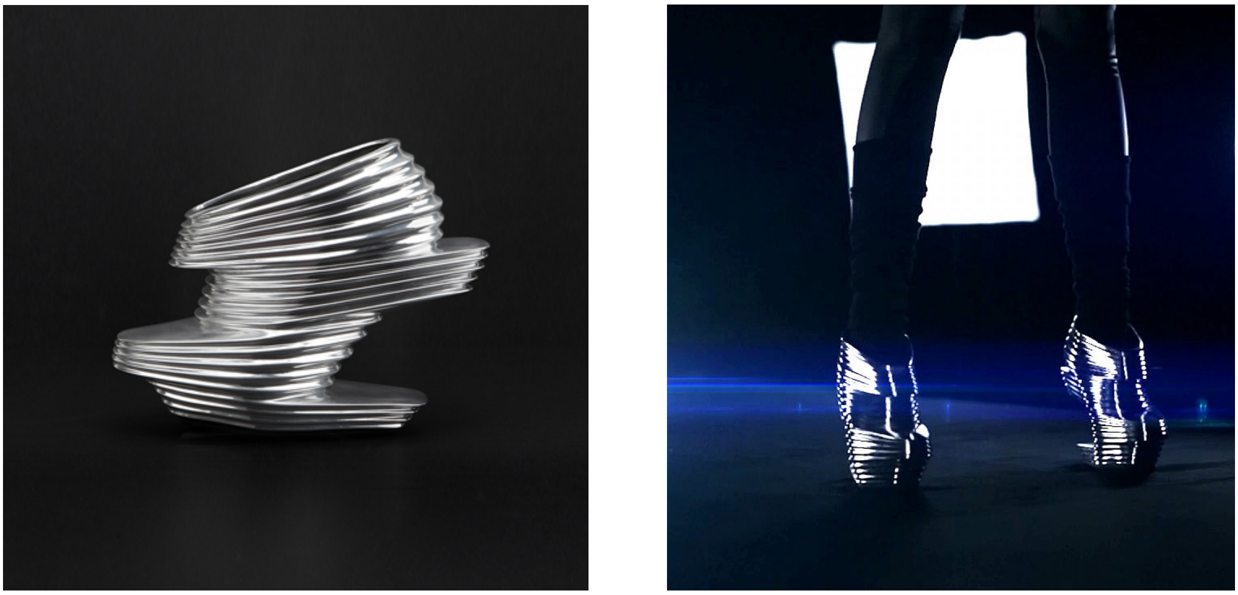


Figure 5_ Zaha Hadid for United Nude, Nova Shoe (2014) (source; NOVA Shoe - Design - Zaha Hadid Architects. https://www.zaha-hadid.com/design/nova-shoe/. Accessed 23 June 2019.

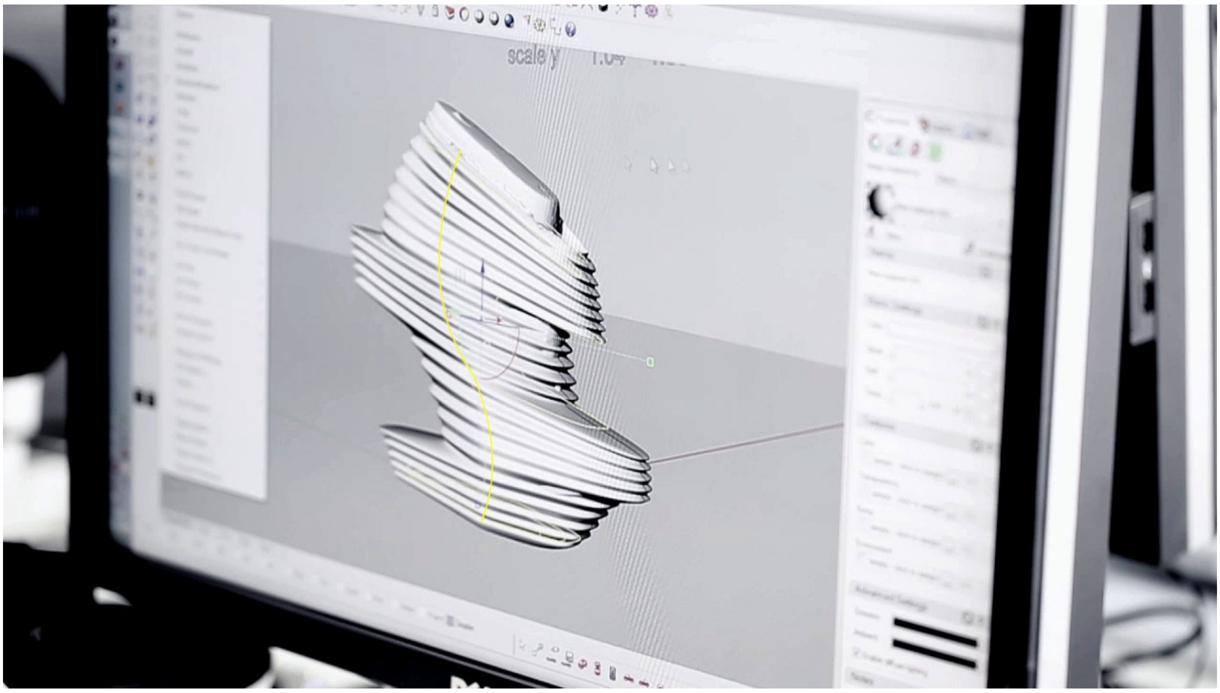


Figure 6_ Nova Shoe model showcasing design process (source; NOVA Shoe - Design - Zaha Hadid Architects. https://www.zaha-hadid.com/design/nova-shoe/. Accessed 23 June 2019.

Continuous Differentiation

Continuous differentiation refers to a certain characteristic of mass-customized,versioned, iterative parametric work, which is "varied instances within an overall group, curve or field maintain their continuity with the neighbouring ones, while uniquely responding to local conditions". (Jabi, 2013)

Characteristics of this particular theme can be in Francis Bitonti's Mutatio Shoe,created by designer's algorithms. Notice how the gold-plated heel's geometry uniquely responds to the shape of leather upper, while maintaining a continuity as an overall group.

Figure 7_Francis Bintonti for United Nude; Mutatio Shoe (2015) (source; Anon 2015. Francis Bitonti 3D-prints gold-plated shoes for United Nude. [online] Dezeen. Available at: <https://www.dezeen.com/2015/09/08/francis-bitonti-3d-printed-gold-plated-mutatio-shoes-united-nude-3d-systems/>, Accessed 19 Dec. 2019)

Mass-costumization

Industrial revolution effectively brought the idea of 'mass production' into reality. Factories nowadays employ robots, that are able to produce unlimited copies of a same prototype. With the dawn of digital fabrication technologies though, one can efficiently alter manufacturing instructions between each object and often at the same cost as mass producing. (Jabi, 2013)

The idea of mass-costumization effectively brought projects situated in fashion design, such as the project "Reinventing the shoes". Commisioned by United Nude and dutch fashion designer Iris van Herpen, along with famous architects and product designers."Reinventing the Shoes' lasted for more than nine consecutive seasons. The are several characteristics that make this project a milestone, as there is a sizable amount of distinctive, custom designs and a big variety of materials digitally fabricated with working prototypes,all in a short period of time. Notable examples concern Zaha Hadid's Flames, Fernando Romero's Ammonite, Michael Young's Young Shoe and Ben van Berkel's UNX2.

Figure 9_ Fernando Romero for United Nude,Ammonite (2015); Design is inspired by nature, human body and cosmos.

(source; “Zaha Hadid’s 3D Printed Flame Heels Among 5 Designs to Re-Invent theShoe.”ArchDaily,.2015,.archdaily.com /620023/zaha-hadid-s-3d-printed-flame-heels-among-5-designs-to-re-invent-the-shoe/.)

Figure 8_ Zaha Hadid for United Nude, Flames (2015); Design is informed by the flickering light of flames, while foot bed is optimized for comfort and support.

(source; “Zaha Hadid’s 3D Printed Flame Heels Among 5 Designs to Re-Invent the Shoe.”ArchDaily,.2015,.archdaily.com/620 023/zaha-hadid-s-3d-printed-flame-heels-among-5-designs-to-re-invent-the-shoe/.)

Figure 11_Michael Young for United Nude, Young Shoe; Design is informed by a unique lattice structure and produces a boot with tactility of lacework that it is durable and flexible at the same time.

(source; “Zaha Hadid’s 3D Printed Flame Heels Among 5 Designs to Re-Invent the Shoe.”ArchDaily,.2015,.archdaily.com/620023/ zaha-hadid-s-3d-printed-flame-heels-among-5-designs-to-re-invent-the-shoe/.)

Figure 10_ Ben van Berkel for United Nude; UNX2 (2015) Design dresses foot in a way si as to make it partially visible in order to highlight the mechanics of foot when walking.

(source; “Zaha Hadid’s 3D Printed Flame Heels Among 5 Designs to Re-Invent the Shoe.”ArchDaily,.2015,.archdaily.com/6200 23/zaha-hadid-s-3d-printed-flame-heels-among-5-designs-to-re-invent-the-shoe/.)

/2.2.4. Generative Design: definition & process diagram

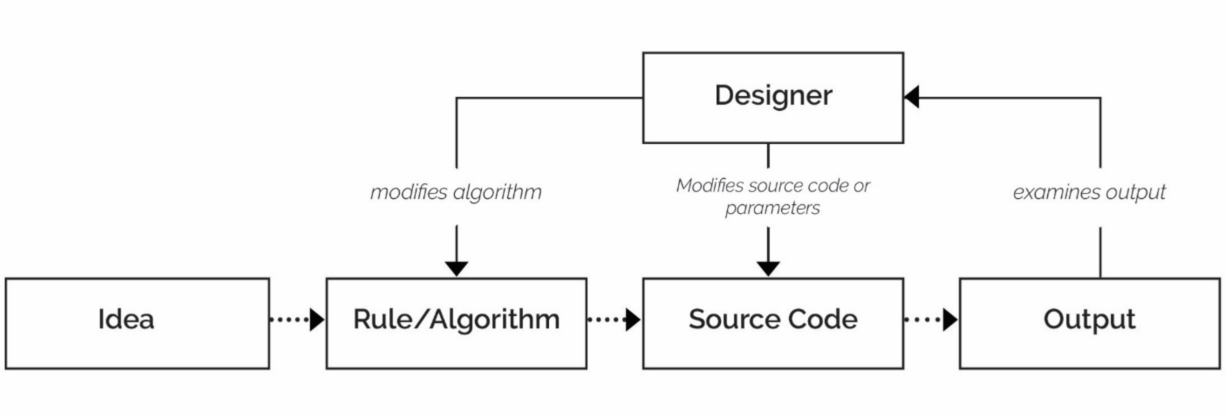


Figure 12_ Hartmut Bohnacker; Generative design process diagram (source; 'H. Bohnacker, J, Laub, B, Groß, C,Lazzeroni (2009),'Generative Gestaltung',www,generative-gestaltung.de

According to book Generative Gestaltung, "generative" design is defined as an iterative process based on a simple idea defined by designers, which is implemented to a rule or algorithm and as a following step, translated to source code, producing successive output. The whole process relies on information exchange between designer and system, as it enables the designer to examine the output and modify the algorithm and the source code. (Figure 12) It is a cyclical operation, meaning the outputs go through a feeback loop (Lazzeroni, et al., 2012).

/2.2.4.1. Fundamental themes of a Generative design system

Morphogenesis

Generative design marks yet another emerging paradigm shift towards algorithmic thinking. In stark contrast to parametric design. which relies on using declared parameters in order to create variation, generative design takes it a step further, by introducing a morphogenetic approach in digital design, effectively mimicking natural processes.

An early definition comes from Celestino Soddu, who brings similarities between generative design and nature into context, He describes "generative" design as "a morphogenetic process using algorithms structured as nonlinear systems for endless unique and unrepeatable results performed by an idea-code, as in nature". (Shoddu, 1994) In other words, designers input ideas as goals and generative software explore all possible permutations to the solution. Indeed, a strong association between those two terms can be found in their etymological meanings, as “morphogenesis” literally means birth of form.

Non-Euclidean Geometries

Branko Kolarevic identifies the type of geometry produced in his description of digital morphogenesis; “the predictable relationships between design and representations are abandoned in favour of computationally generated complexities. Models of design capable of consistent, continual and dynamic transformation are replacing the static norms of conventional processes. Complex curvilinear geometries are produced with the same ease as Euclidean geometries of planar shapes and cylindrical, spherical or conical” (Kolarevic, 2003)

Autonomy

Michael Hensel sees generative design as a “self-organization process, underlying the growth of living organisms, from which designers can learn” (Hensel, et al., 2006; Kolarevic, 2003),

Parametric Design

Rivka and Robert Oxman identifies parametric design as key concept informing generative design (Oxman & Oxman, 2013)

A bottom-up process

Jessica Rosenkratz sees Generative design as a bottom-up process, (Rosenkrantz & Louis-Rosenberg, 2017)

/2.2.5. Examples of Generative Fashion Design

Examples of Generative fashion design show promise in their ability to interpret generative design process and its properties, in diverse ways. They also showcase powerful new ways of user engagement, leading to innovative, costumized products,

The purpose of this section is to present various steps in user engagement in order of importance, as well as highlight how designer and user interact with each system. Furthermore, these projects highlight evolutionary steps of user input as the first project introduces user manipulation in a simplified user interface, enabling various levels of engagement according to user skill level, the second one captures user gestures and simulates them real time, while the third one reaches the climax, by introducing on body manipulation.

/2.2.5.1. 3d software & user manipulation; Project Cell Cycle

Co-founded by Jessica Rosenkrantz and Jesse Louis, Nervous System is a "generative design studio that works at the intersection of science, art, and technology" using novel computer generated design processes and digital fabrication in order to realize new products. A particular field of action is fashion design items. (Nervous, 2019; Rosenkrantz & Louis-Rosenberg, 2017)

About Nervous system

<u>Agenda</u>

1. Inspiration from natural phenomena, dynamic systems and digital fabrication
2. User costumization as opposed to mass production, investment in a single form will not work.
3. New possibilities found in computer <u>controlled manufacturing techniques</u>, such as laser cutting and 3d-printing, since they enable complex computer generated geometries.
4. Precision manufacturing in the hands of everyone and at a similar cost as mass-mass produced ones.
5. The problem <u>Software(CAD)</u>; sofware is expensive, difficult to use, does not take fully advantage the variation digital manufacturing makes possible.

According to Jessica Rosenkrantz, Nervous System focus is on generative design, describing it as bottom-up approach, in direct contrast to the enstablished approach of static designs happening nowadays. She sees value in playful interactive systems engaging users in a dynamic way. Nervous System is interested in “growing” designs as opposed to creating static designs.

Project Cell Cycle (2009)

Idea/Geometry

Project Cell Cycle finds its inspiration inside the structural efficiency of radiolarians, Radiolarians use a small amount of silica, creating cellular skeletons. A small amount of silica is able to produce large strong structures making garticularly good for 3d printing: by minimizing material volume, it makes it also affordable. This is particularly useful for jewellery and garment design.

Products

Rings,cuffs, bracelets,pedants

The process

The project effectively marries Computational Design and 3d printing. Core in its generative design system is the Cell Cycle Web App, where anyone can costumize their own rings, bracelets or sculpture for 3d printing.

Inside Cell Cycle web app (Table 1), the process goes as follows;

1. Inside app you scuplt, twist, shape, subdivide cells and the system responds by transforming a mesh, to an intricate bespoke structure.
2. User interacts with a simplified interface that encourages direct geometry manipulation with familiar elements like sliders and buttons (Figure 14)
3. The visual feedback is instant enabling user to examine result and react accordingly.
4. You can choose among 4 different products; rings (Figure 16),cuffs (Figure 15),bracelets (Figure 18) or pedants, Final output can be immediately printed out

It is effectively an open-ended approach, meaning there is freedom to explore form in such a way, that it can also provide impractical results. all for the sake of exploration. On the other end, Nervous System assesses output and modifies source-code. The aim is to create mass-customized, open-ended experiences with web apps as large design spaces, requiring user input, with muliple levels of engagement and different user skill levels. (Rosenkrantz & Louis-Rosenberg, 2017)

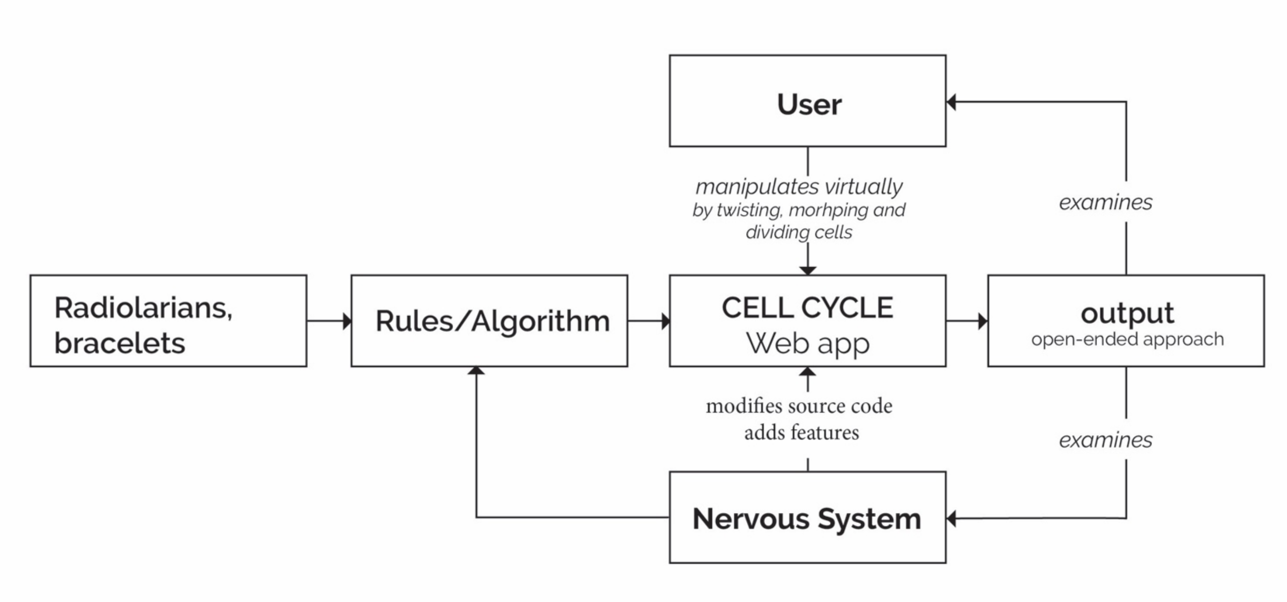


Table 1_ Project Cell Cycle design process, utilizing Generative Gestaltung process diagram

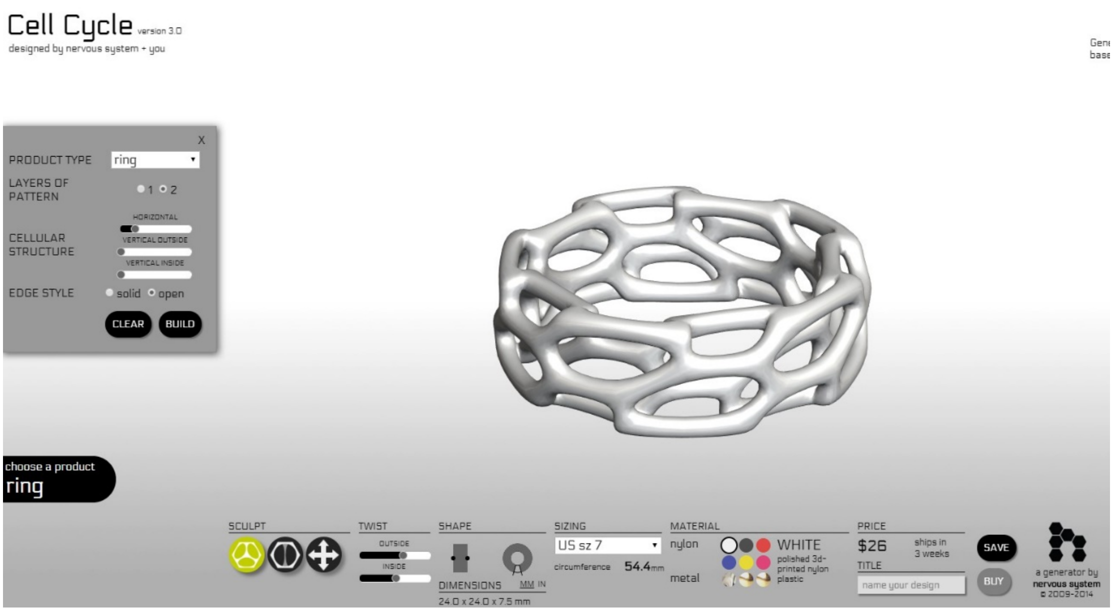


Figure 14_ Cell Cycle web app user interface; direct geometry manipulation with familiar elements like sliders and buttons (source; Cell Cycle: 3d-Printable Jewelry Design App Inspired by Microscopic Cellular Structures. https://n-e-r-v-o-u-s.com/cellCycle/. Accessed 22 July 2019.)

Figure 16_ Sterling silver cast rings from 3D printed wax (source; System, Nervous. “97-Cell-Cycle-Rings-Sterling-Silver.Jpg.” Projects by Nervous System, http://n-e-r-v-o-u-s.com/projects/index.php?/albums/cell-cycle-jewelry/content/97-cell-cycle-rings-sterling-silver/. Accessed 22 July 2019.)

Figure 15_ 3D printed stainless steel spiral cuffs (source; System, Nervous. “Spiral Cuff.” Projects by Nervous System, http://n-e-r-v-o-u-s.com/projects/index.php?/albums/cell-cycle-jewelry/content/spiral-cuff/. Accessed 22 July 2019.)

Figure 18_ 3D printed nylon plastic bracelet, polished and dyed black (source; System, Nervous. “86-Cell-Cycle-Interstice-Bracelet-in-Black.Jpg.” Projects by Nervous System, http://n-e-r-v-o-u s.com/projects/index.php?/albums/cell-cycle-jewelry/content/86-cell-cycle-interstice-bracelet-in-black/. Accessed 22 July 2019.)

Figure 17_ 3D printed nylon plastic, polished and dyed black (source; System, Nervous. “57-Cellular-Pendant.Jpg.” Projects by Nervous System, http://n-e-r-v-o-u-s.com/projects/index.php?/albums/cell-cycle-jewelry/content/57-cellular-pendant/. Accessed 22 July 2019.)

/2.2.5.2. 3d scanning & user gestural manipulation; Project Reverb

Co-founded by Madeline Ganon and Julian Sandoval, Atonaton is a research studio, who develops applications that communicate with machines in unique new ways that capture imagination.

About Studio Antonaton

Agenda

Studio Antonaton is inspired by the body itself as a dynamic interface. Field of focus is a particular characteristic our body has; it continuously casts information to our surroundings using gestures, body language and proximity.

1. Physical interaction with a virtual design process that links directly through a 3d printed output
2. Problem: Software, insufficient tools for the body (CAD)
3. Problem: Body has complex curves and non-euclidean "contours", there are also different body types and variation can be a time consuming task
4. In need of body centric design tools to capture and engage the body.

Antonaton employs projection mapping tools, and depth sensing scanners to capture body's spatial transmission, translate and recognize into actionable information. That same information 'feed' specialized software, powered by autonomous geometries, which can be manipulated by user real-time, using gesture navigation or on-body manipulation. (Gannon, 2017)

Project REVERB

Ideas/Geometry

Reverb uses a semi-autonomous geometry built from spring skeleton structures, useful to minimize error in complex hand gestures. Spring skeleton structures are constructed as a closed mesh,meaning no matter how complex movement is, geometry will always be exportable as a valid 3d printing mesh. Movement is captured by a chronomorphologic technique, doing composite recordings of hands' movement, (Figure 19) in a 3d virtual enviroment. (Atonaton, 2018)

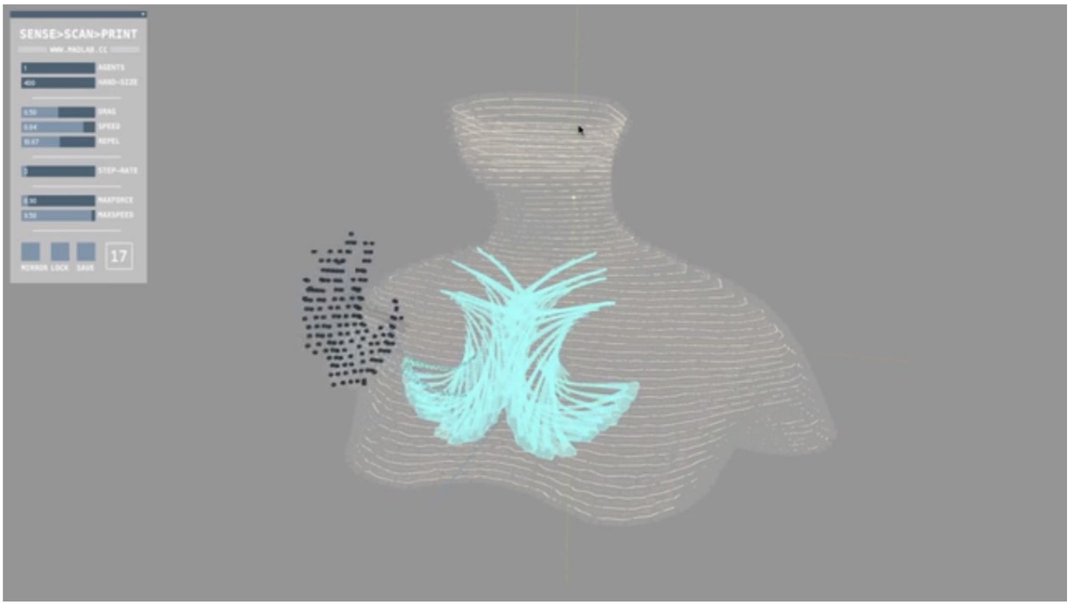


Figure 19_ Reverb's modelling interface, shows composite recordings of spring skeleton geometry in light blue, responding to hand movement in a 3d enviroment (source; "Reverb." ATONATON, https://atonaton.com/reverb. Accessed 22 July 2019.)

<u>Products</u>

Necklaces, Collars, Bracelets

<u>Process</u>

Reverb is a fabrication aware design tool translating hand gestures into intricate geometries that can be immediately 3d-printed out (Table 2):

1. A depth sensor captures users body part and into a 3d scan in virtual enviroment.
2. The same sensor tracks and recognizes user's hand gestures allowing them to reach the computer and interact with autonomous geometry inside Reverb
3. To begin crafting, user moves their hand and the system records the mesh of his base module as it is manipulated through spacetime (Figure 20)
4. As user continues to guide the geometry virtually, their gestures become complex lattice structures (Figure 21) around their digitized body. (Gannon, 2017)

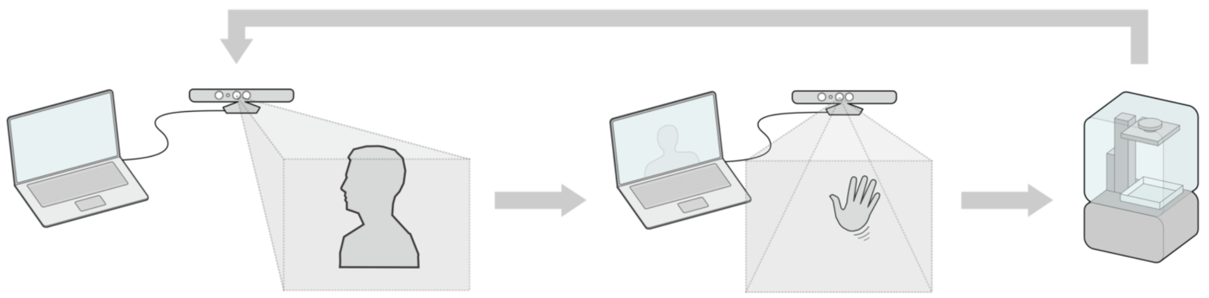


Figure 20_ Interconnecting physical and digital words; Illustrative diagram,showing user interaction with the system. (source; "Reverb." ATONATON, https://atonaton.com/reverb. Accessed 22 July 2019.)

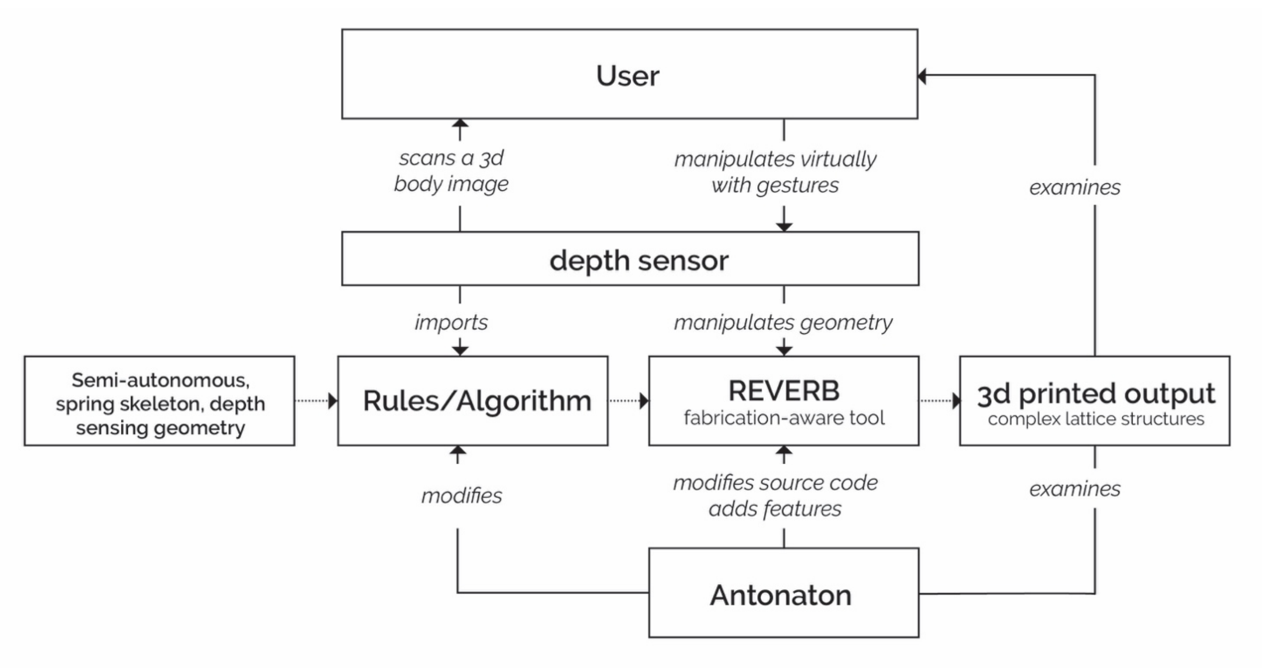


Table 2_ Project Reverb design process, utilizing Generative Gestaltung process diagram

Figure 21_Project Reverb; Final Product and variations (source; “Reverb.” ATONATON, https://atonaton.com/reverb. Accessed 22 July 2019.)

/2.2.5.3. On body user manipulation; Project Tactum

Geometry

Tactums’s interactive geometry is built from features extracted form the arm. Sensor handles all interactions, detects gestures, and also extracts geometry by segmenting the wrist (Figure 22). Segementation enables Tactum to parametrically adapt to various body types. (Gannon, 2017)

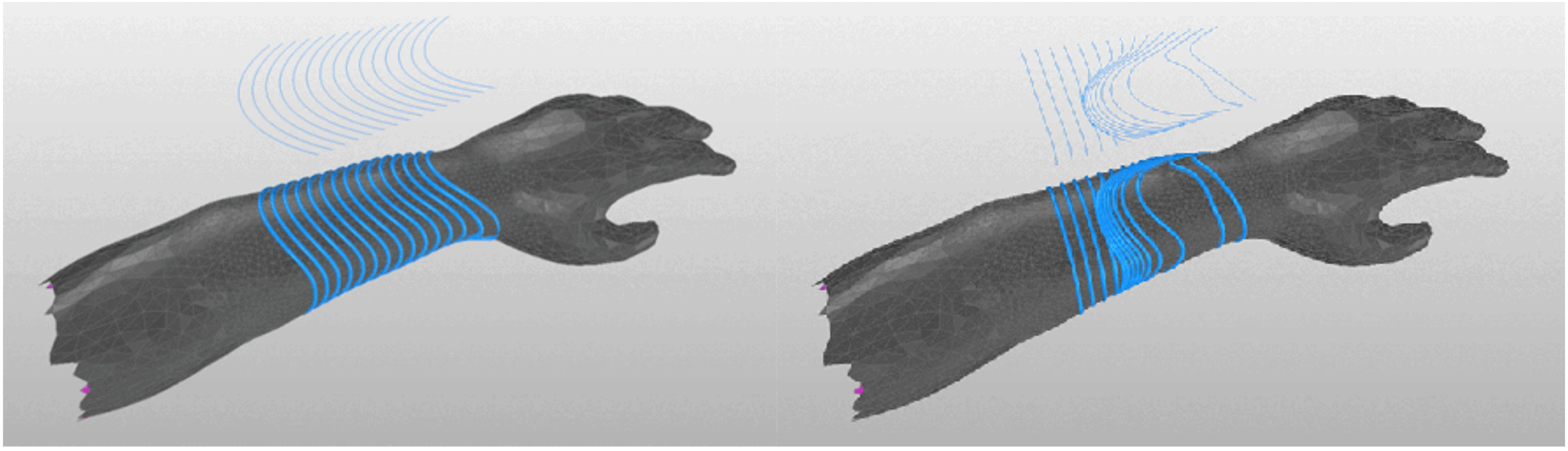


Figure 22_ Algorithm wrist segmentation strategy (source; Anon 2019. Tactum. [online] ATONATON. Available at: <https://atonaton.com/tactum>, Accessed 19 Dec. 2019).

Process

Unlike previous solutions described, which use a traditional 3d printing enviroment, Tactum allows for only ready to print, 3d-printing solution, with arm as an interface of reiteration (Figure 23).This is particularly useful, as user manipulates the geometry in a 1:1 scale, using natural gestures (Gannon, et al., 2015).

In detail, a depth sensor tracks tactile feedback happening on arm. Upon arm recognition, interactive fabrication aware geometry is projected on users arm, allowing him to manipulate it, using supported gestures, such as rubbing, dragging and pinching (Figure 24). When desired geometry is achieved,user closes hir/her hand to export a ready to print design (Gannon, 2017).

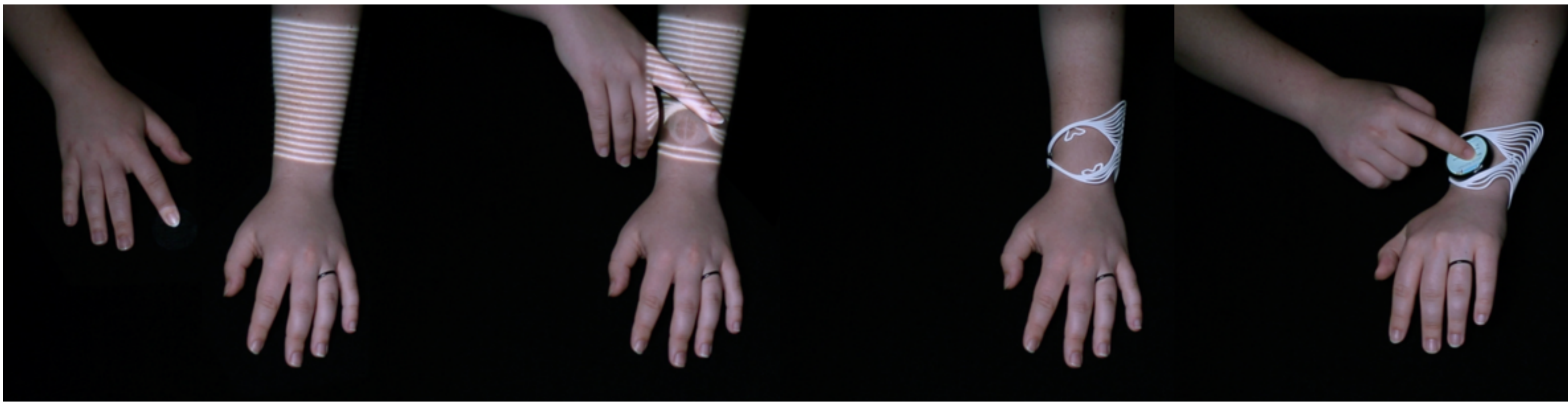


Figure 23_ Sequence of photos capturing moments during on body geometry manipulation, using arm as a medium (source; Anon 2019. Tactum. [online] ATONATON. Available at: <https://atonaton.com/tactum>, Accessed 19 Dec. 2019).

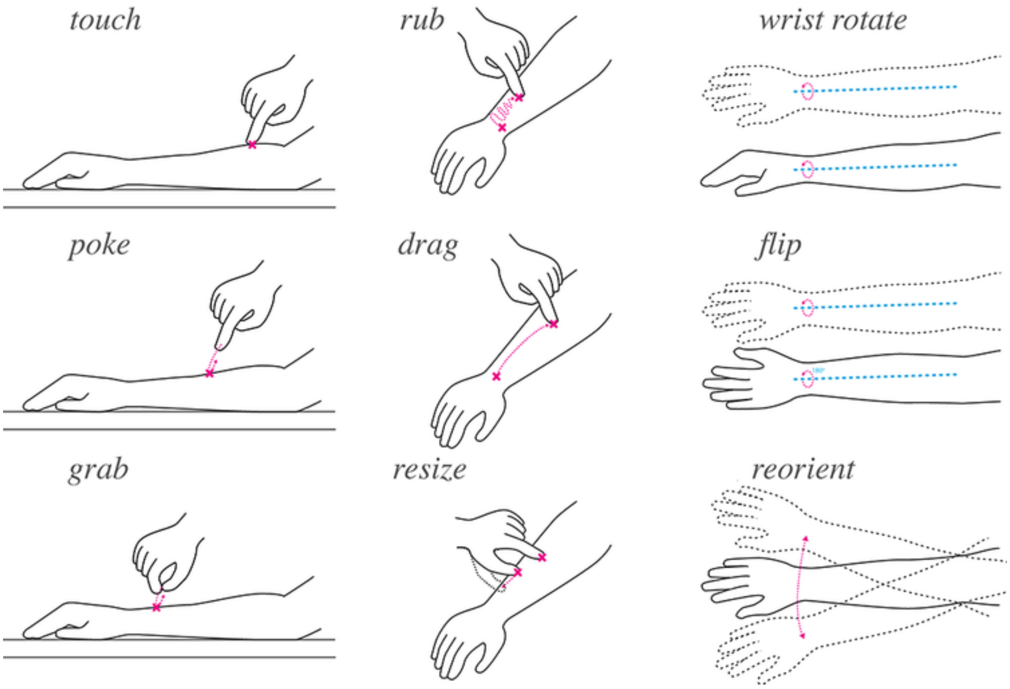


Figure 24_ Supported Gestures (source; Anon 2019. Tactum. [online] ATONATON. Available at: <https://atonaton.com/tactum>, Accessed 19 Dec. 2019)

/2.3/ Outcomes in Computational Fashion Design

Concequently, there are evidence to suggest that Fashion design is undergoing a major paradigm shift in terms of its underlying processes, embracing an era of computer generated geometries and a shift towards algorithmic thinking, by describing the logic and intent of a design proposal, rather the form of proposal instead.

What is more, there are two clear directions, as part of the outcome of exploration, emerging in current chapter;

/2.3.1. Iterative fashion design, designer as a coder, mass costumization

First direction is process-driven; Computational design and its various forms of expression (parametric and generative design), directly influence fashion design and transform it into an iterative design process, by inheriting fundamental themes and properties in term of its morphology. As such, fashion design is characterized by non-linear processes of form generation, with computer generated non-euclidean geometries, all while becoming compatible with advanced production technologies.

Furthermore, it is safe to assume a change in roles happening between designer and end user. On one hand, designer is occupied by the task of creating processes, utilizing computational design and its forms of expression, instead of focusing on form itself. On the other hand, user assumes an active role in making decisions, engages with creative processes by manipulating geometry in revolutionary new ways, as shown from paradigms such as Project cell Cycle, Project Reverb and Project Tactum, thus leading towards mass-costumized fashion design products.

/2.3.2 Jewellery and wearables design; efficient production

Second direction is paradigm-driven; by carefully analyzing case-studies of projects utilizing computational design and its forms of expression, research initially confirms the deep, interconnected links between computational design and digital fabrication technologies. As such, in order to realize new products, those should work in harmony, by complimenting one another.

Additionally, evidence from projects also describe in detail the current status of digital fabrication technologies in fashion design; as of now such technology can be utilized efficiently to produce fashion design products in the scale of jewellery, wearables and accessories, since their size generally conforms to average 3d printer bed size. Finally key factor is the strategic selection of geometry in use, as shown from paradigms in Project Cell Cycle, with effective use of Radiolarians in order to minimize material volume.

With these two directions as a given, the following chapter raises questions as to how computational fashion design and digital fabrications technologies accommodate a wider range of design proposals concerning the body, effectively contributing to the wide range of products, part of fashion design portfolio.

3/ Computational Fashion Design & 3d Printing: integration in a wider fashion portfolio

Outlined in previous chapter, research concludes that, at the dawn of computational fashion design, current digital production technologies can be utilized efficiently under the scale of wearables, jewellery and fashion accessories. As such, current chapter analyzes how computational design and digital fabrications technologies accommodate a wider range of design proposals concerning the body, effectively contributing to a wide range of products, part of fashion design portfolio.

/3.1./ Outlining 3d Printing limitations; bed size, nature & material limitations

Apart from the creation of wearables and jewellery for aesthetic reasons, fashion design is traditionally occupied into giving solutions to a much wider spectrum of design proposals concerning the body, These design solutions are characterized by bigger size dimentions (apparel design) and sensibilities in choice of materials suitable for bodily movement, perfect fit and comfort (apparel & footwear design). Current state of 3d printing process, makes for a problematic situation for the following reasons;

According to Neil Leach, 3d printing capabilities are currently subject to size constraints, associated with 3d printers' bed size. He explains that any bed size increase out of the range of 'standardized' ones, leads to exorbitant amounts of elevated cost, threatening the prospect of mass-costumization. He also suggests that there is a strong connection between 3d printed object size and the inherent strength of the material used in 3d printing processes. He further explains that the inherent strength of the material remains the same, regardless of any size increase.

Speaking of size , Neil Leach brings analogies from mathematics and biology into spotlight; "it appears, an increase in size, leads to an exponential increase in volume & weight; by a simple mathematical principle, if we were to measure a 10x10x10cm cube, and double its dimensions, one would find that volume increases by a factor of 8. In a similar fashion, if we hypothetically try and scale up an elephant two times, its volume and weight would increase 8 times as well, with compromises to its structural performance, as the ratio between the intrinsic strength of its skeletal structure and its weight would be decreased". (Leach, 2017)

In tune with Neil Leach, Michael Fowler also explains the properties of the material bone; "The intrinsic strength of the material bone is made from in animals of all sizes (Calcium apatite embedded in a matrix of collagen) is about the same. The strength of a bone is proportional to its cross sectional area." (Fowler, 2004)

In essence, it seems that a being such as an elephant scaled two times larger could simply not exist in nature, due to its inability to sustain its own weight, since the intrinsic strength of the material bone remains the same. Translating back to 3d printing, it seems that materials are subject to same principles, they are designed to perform adequately under certain sizes and circumstances.

/3.2/ Limitations & workarounds in Computational Fashion Design

It appears such factors are already being taken into consideration. The prospect of efficient 3d printing is part of a wider creative effort happening across disciplines in design. Architecture is one of those professions with a wide range of experience in minimizing 3d printing costs and experimenting with new sets of materials. Examples of large scale 3d printing projects in architecture, such as "Flotsam & Jetsam" by SHoP Architects, exhibit freeform 3d printing processes of components on a large-bed printer (Figure 25), later assembling them into a pair of pavilions (Figure 26). Highlights of this project consist successful workaround solutions around bed size limitations, also reaffirm the strong relationship between computational design and digital fabrication; the fittings between components are designed computationally, in order to ensure successful assembly later. (SHoP, n.d.)

Scaling down to fashion design, we see upcoming projects following similar strategies of computational fitting and assembly of the components in order to realize full scale, finalized products. Furthermore. we see how these projects explore additional strategies specifically targeted at fashion design and its characteristics, such as the need for comfort, perfect fit and flexibility in materials for bodily movement.

At this point, research highlights collaborations and explores outcomes found in footwear and apparel design projects. First section covers UN Studio's "Reinventing the Shoes" project, while second section covers a series of smaller collaborative projects in apparel design, happening between Niccolo Casas, Iris van Herpen and various disciplines. Third section concerns project Kinematics from Nervous System, pursuing an exclusive agenda in apparel design. All projects are presented in an order of importance; the idea to realize evolutionary steps towards integrating Computational Fashion design workflows with efficient 3d printing processes, covering a larger part of fashion design portfolio.

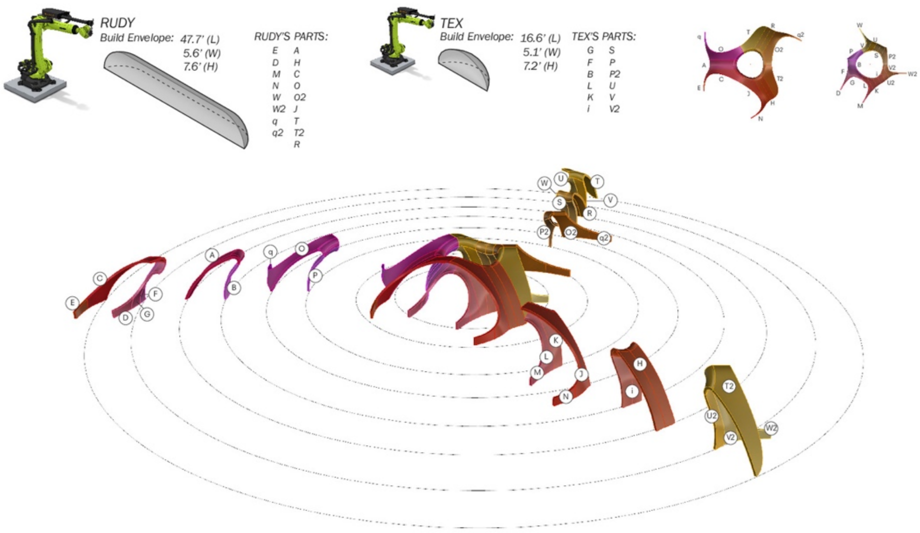


Figure 25_ Industrial Robots Rudy and Tex fabricate components made on a large-bed printer, weighting nearly 300KG, (source; Flotsam & Jetsam | SHoP. https://www.shoparc.com/projects/design-miami/. Accessed 22 July 2019.)

Figure 26_ 'Flotsam & Jetsam' by SHoP Architects; a pair of pavilions showcasing novel 3D-printing techniques , (source; Flotsam & Jetsam | SHoP. https://www.shoparc.com/projects/design-miami/. Accessed 22 July 2019.)

/3.2.1 Footwear Design: traditional materials and comfort

Research on footwear design covers UN Studio's co-founder Rem Koolhaas comments concerning the series of projects "Re-inventing Shoes". United Studio was one of the first studios to test 3d printing for the first time, leading to several early collaborations with 3D Systems, the company founded by inventor of 3d printing, Chuck Hull. These projects, also give an early glimpse on capacities and limitations 3d printing offers in this field.

/3.2.1.1. Common 3d printing processes & comfort; Project "Re-inventing shoes"

According to Rem Koolhaas, 3d printing benefits limited quantity mass-costumized products, with much greater flexibility in terms of complexity and shape. What is more, current tehnologies offer limited choices in terms of comfortable materials. (Koolhaas D, 2017)

The process

- 3d printing technology of choice was selective laser sintering (SLS) as opposed to stereolithography (SLA), reasons directly linked to material behaviour. That is because the method of choice uses polyurethane rubber and nylon known for their softness, as well as informed by the ability of SLS process to solidify rubber from melted powder fragments. On the contrary SLA processes solidify from a “liquid resin”, which is more sensitive to heat, leading to possible deformation.

- Applications of SLS printed rubber in footwear showcased ability to house the foot effectively, but its ‘sandpaper’ texture made it later uncomfortable, only being able to use it for a quick photoshoot.

- Notable project was Mutatio Show in collaboration with Francis Bitonti as marks the sum of the collaborative effort between various disciplines (Figure 27); The show is a combined gold plated SLS nylon printed with a non-3d printed leather upper, as it was more practical to use tradidional materials I areas that touch the skin. The result was a shoe being able to provide comfort for an acceptable amount of wearing time. (Koolhaas D, 2017)

Figure 27_ Francis Bintonti for United Nude; Mutatio Shoe (2015) (source; Anon 2015. Francis Bitonti 3D-prints gold-plated shoes for United Nude. [online] Dezeen. Available at: <https://www.dezeen.com/2015/09/08/francis-bitonti-3d-printed-gold-plated-mutatio-shoes-united-nude-3d-systems/>, Accessed 19 Dec. 2019)

/3.2.2. Apparel Design; Knitting, traditional & digital craftsmanship

Research on apparel design begins by investigating Niccolo Casas collaboration with fashion designer Iris van Herpen in a series of smaller projects directly linked together, All these projects show promise in their ability to overcome 3d printing limitations and marry traditional and digital design processes.

Niccolo Casas describes these three different evolutionary phases as “exploration”, “articulation” and “integration”. Initial phase ‘exploration’ covers the creation of Magnetic Motion Dress, investigating novel qualities found in additive manufacturing technologies and 3d software. Second phase “articulation” is characterized by the inclusion of kinesis to support bodily movement in the form of Hacking Infinity Dress. Finally, “integration” marks the creation of a series of dresses called “Lucid” Collection, as a result of the experience gained in each phase. (Casas, 2017)

Throughout project, van Herpen’s role becomes pivotal; her field of expertise is to combine traditional and radical materials as well as known, tested and radical production techniques, particularly useful in overcoming dead ends, related to manufacturing processes. (van Herpen, 2019)

Key factors driving these projects are formulated in an extensive agenda outlined as follows;

Agenda

According to Casas, the new digital revolution is influenced from parametric design and production processes borrowed from architecture, engineering and computer graphics, while at the same time create a sense of “performative aesthetics”. “Performative aesthetics” brings to fashion design a paradigm shift, informed by computational design tools, advanced fabrication technologies, while create new hybrid disciplines emerging from both artistic and scientific fields.

Furthermore, his collaboration with Iris van Herpen and various disciplines is grounded on common interests such as the 3d dimensionality of the body, and 3d dimensionality around the body. Apparel design becomes an area of interface and experimentation; spaces, dress and person are integrated systems but still independent. Furthermore, additive manufacturing and future materials may help enhance production when needed and reduce waste. (Casas, 2017)

/3.2.2.1. Exploring 3d printing and software; 'Magnetic Motion' Dress

Collaboration: Niccolo Casas (architect) - Iris van Herpen (Fashion Designer) - Jolan Van Der Wiel (artist)

Ideas-Geometry

Experimentations on magnetic fields and Ferro fluids created by artist Jolan van der Wiel, later translated on simulation in 3d software by Niccolo Casas, by examining embodiment of the dynamic forces causing attraction and repulsion.

Process

1. Material of choice was "3d Printable material Accura" in order to capture and solidify motion. (Figure 28) "3d printable material Accura" is a stereolithography (SLA) material, by 3d Systems, known for its ability to create translucent, refined, and high detailed forms. It also encourages a creative play between light and shadows, captured in a crystalized ice effect, something unable to do with traditional materials. The structure of cloth showcases offset patterns of magnetic growth.
2. 3d printed as a front and back (total 81 hours), later assembled by digital and traditional craftsmen working and refining together (8 hours). (Figure 29)
3. After finalizing dress's 3d design, Casas and Iris van Herpen, took a scan of models dimensions (Figure 30) in order to match the final file ready to print. (Casas, n.d.)

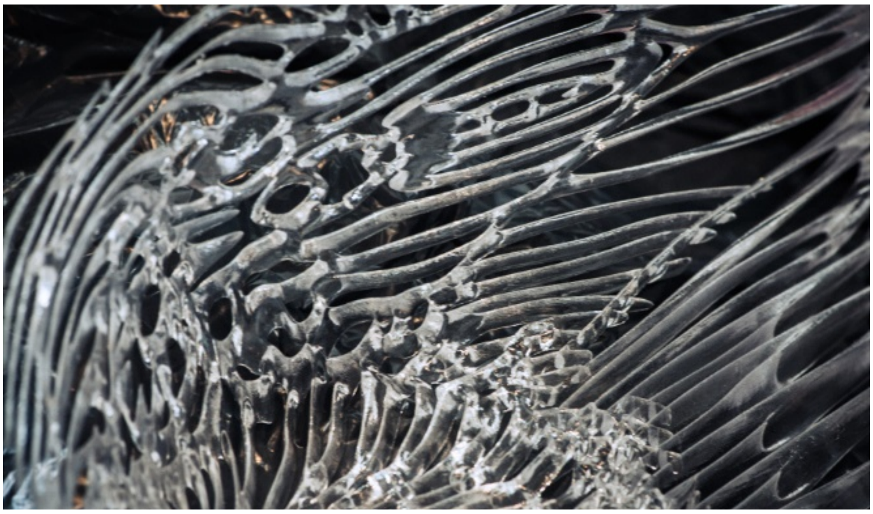


Figure 28_ "3d Printable material Accura" showcasing offset patterns of magnetic growth (source; MAGNETIC MOTION - Niccolocasas. http://www.niccolocasas.com/MAGNETIC-MOTION. Accessed 2 Oct. 2019)

Figure 29_ Magnetic Motion Dress; 3d printed as a front and back (source; MAGNETIC MOTION - Niccolocasas. http://www.niccolocasas.com/MAGNETIC-MOTION. Accessed 2 Oct. 2019.

Figure 30_ Designed specifically for Dutch model Iekeliene Stange (source; MAGNETIC MOTION - Niccolocasas. http://www.niccolocasas.com/MAGNETIC-MOTION. Accessed 2 Oct. 2019.)

The result was a couture piece that effectively houses the body. It acts as a semi rigid shell for the body; the dress, the body and surroundings co-exist in harmony, but all remain autonomous. Magnetic Motion Dress represents an early fruit from the collaborative effort, focusing on new techniques, materials and software instead of practicality; it allows only for partial movement. Upcoming Hacking Infinity Dress project addresses this issue. (Casas, 2017)

/3.2.2.2. Supporting bodily movement; ‘Hacking Infinity’ Dress

Current phase is described by the inclusion of kinesis; functional properties leading to support bodily movement.

Ideas

In search of kinetic properties,complimenting bodily movement. The problem is the loss of flow in design as the dress becomes fragmented in order to complement movement.

The process

1. Developing a knitting system in order to overcome the problem of partial movement in earlier Van Herpen’s sculpted pieces; in detail 4 panels of interconnected bits were developed this time with small teeth locking into positions creating a dynamic set.(Figure 31)
2. Stereolithography processes using the same “3d Printable material Accura”, but in unique pieces; all 6.556 components are different.
3. 3d Systems and their team optimized a ready-to-print 3d file, in order for 3d printer to print those components (200 Hours) and manual support removal upon 3d printing (2 hours). (Casas, 2017)

Figure 31_ Knitting system comprised interconnected parts made out of “3d Printable material Accura” (source; HACKING INFINITY - Niccolocasas. http://www.niccolocasas.com/HACKING-INFINITY. Accessed 3 Oct. 2019)

Figure 32_ Hacking infinity Dress comprised of 6.556 components in order to overcome the problem of partial movement (source; HACKING INFINITY - Niccolocasas. http://www.niccolocasas.com/HACKING-INFINITY. Accessed 3 Oct. 2019)

Figure 33_'Hacking infinity Dress'; inclusion of Kinesis (source; HACKING INFINITY - Niccolocasas. http://www.niccolocasas.com/HACKING-INFINITY. Accessed 3 Oct. 2019)

The result was a couture piece that effectively reaches a milestone. Hacking Infinity Dress adheres to the concept of kinesis in order to support bodily movement by developing a complex knitting system of components, created using traditional and digital craftsmanship. (Figure 33)

/3.2.2.3. Technology fused with handcraft; 'Magma' Dress

Third phase marks the sum of all collaborative effort. After gaining years of experience, collaboration puts all its effort into combining traditional and digital craftsmanship in a series of dresses called "Lucid" collection. Magma dress, part of "Lucid" collection, is a characteristic example of marrying rigid materials with flexible ones.

<u>The process</u>

1. Concerns a 3d printed dress with a combination of TPU flexible material and polyamide rigid printings on top. (Figure 34) These materials are 3d printed and while combined with traditional craftsmanship, they help create unprecedented capabilities in flexibility and adaptability and no problems in stretching.
2. Favourite choice of assembly is again a sophisticated knitting system; 6,052 unique 3d printed pieces are stitched together, while they differentiate in body's various positions; the algorithms were made to include both the nature of materials as well as the gestures of the body. (Casas, 2017)

Figure 34_'Magma' Dress; combinations of flexible and rigid materials (source; MAGMA DRESS - Niccolocasas. http://www.niccolocasas.com/MAGMA-DRESS. Accessed 4 Oct. 2019.)

Figure 35_ (right) 'Magma' dress; 6,052 unique 3d printed pieces are stitched together to compliment complex body position (source; MAGMA DRESS - Niccolocasas. http://www.niccolocasas.com/MAGMA-DRESS. Accessed 4 Oct. 2019.)

Figure 36_ (left) 'Magma' dress; aesthetic complexity and structural variation. (source; MAGMA DRESS - Niccolocasas. http://www.niccolocasas.com/MAGMA-DRESS. Accessed 4 Oct. 2019.)

The result is a couture piece that combines materials and techniques that were developed in earlier phases of the collaboration effort. It marks the epitome of aesthetic complexity and structural variation, true to vision of “performative aesthetics”, effectively fusing handcraft with technology.

/3.2.3. Apparel design; digital compression, folding and simulation

Research on apparel design concludes by covering Nervous Studio's project Kinematics and its ecosystem of web apps working in tandem in order to realize, final ready-to-print garments. Project Kinematics marks a radical departure from workaround solutions found in collaborative projects from Niccolo Casas and Iris van herpen; the idea is to print the cloth in one piece and the driving force behind it sits at the crossroads between computational design and digital fabrication. Key interests are outlined in the form of an exclusive agenda below;

<u>Nervous Focused Agenda for the body</u>

1. Triptych; Computational Design, Digital Fabrication, Simulation all working in tandem.

2. Interest in how clothing may be created in a different way and how 3d printing impacts form, when creating clothes in their entirety, in one piece.
3. Interest in perfect fit clothing, mass-customized to one's body and shape.
4. Interest in 3d-dimensional aspect of body structure
5. Interest in creating a new process of 3d printing a 3d dimensional form as opposed to current process of carefully piecing flat materials together. (Rosenkrantz & Louis-Rosenberg, 2017)

Nervous System; Project Kinematics (2013)

<u>The process</u>

On one hand, the project is based on the idea of emulating the process of creating textiles. Textiles are traditionally human constructions as raw materials are transformed to have completely new properties. In case of Kinematic materials, geometry is prioritized as opposed to materials since the idea is to implement a production with 3d printers. The reason is that 3d printing enables computationally constructing materials, while complex configurations of matter can result in meta-materials.

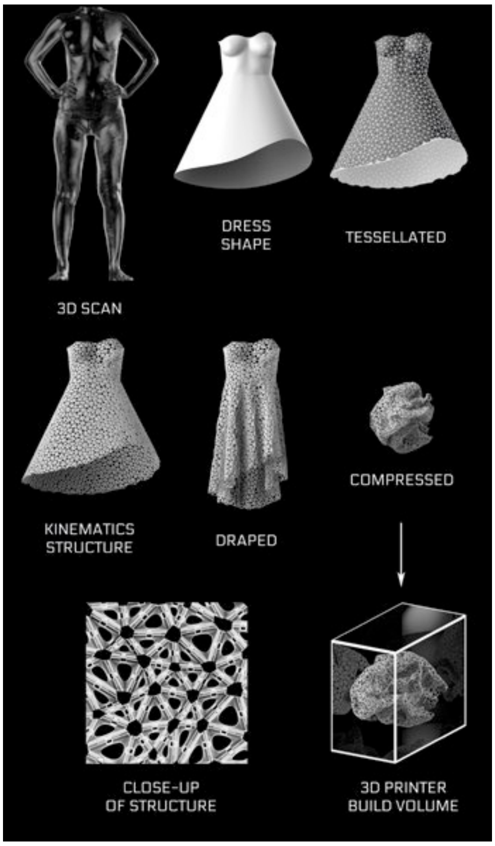


Figure 37_Nervous sytem new workflow proposal, allowing dress to printed in one piece (source; System, N., 2019. 02-kinematics-concept-dress.jpg. [online] projects by Nervous System. Available at: <http://n-e-r-v-o-u-s.com/projects/index.php?/albums/kinematics-concept/content/02-kinematics-concept-dress/> Accessed 26 Nov. 2019.)

On the other hand. Nervous system employs a smart folding strategy of compression via Kinematics Fold app by compressing Kinematics garments in a smaller form for efficient fabrication. Furthermore, the intention is to emulate traditional human activities when it comes to clothing; the idea of folding clothes in order to save space is elevated on 3d printing, The goal is to start printing larger structures by folding computationally, and after 3d printing, garments unfold in one piece.
(Figure 37) Throughout project, user once again is at the forefront of the decision making process; inside Kinematics Clothes app he/she sculpts,twists and morphs. as well as imports 3d scanning data of his/her body shape. (Rosenkrantz & Louis-Rosenberg, 2017)

<u>Materials/Geometry</u>

1. Based on triangular shaped components connected by hinges creating a tiled surface.
2. Result is a structure identified as a crossbreed between soft and hard materials, Although each component is rigid, they all act as a continuous fabric, conforming to bodily movement, in a flexible way.(Figure 38)
3. Kinematic textile is not uniform. Its triangular shaped components applied are different in size and type and can alter in “shape, rigidity, porosity and pattern”. (Nervous, 2014)

Figure 38_ Project ‘Kinematics’ materials acting as a continuous fabric, conforming to bodily movement (source; System, Nervous. “Jump-Composite.Jpg.” Projects by Nervous System, http://n-e-r-v-o-u-s.com/projects/index.php?/albums/kinematics-dress-1/content/jump-composite/. Accessed 7 Oct. 2019.

Web apps

Products Dresses, skirts and shirts.

The process

Kinematics Clothes app;

1. Using parametric modelling technology from Body Labs, users import their body dimentions and then the entire process is taken 3d. “What you see is what you get as a result”. (Figure 40)
2. App designs 3d garments customized to fit to ones shape and user is at the forefront at the decision making process by sculpting the sillouette and hemline, all while determining garment’s tiled fabric structures. (Figure 39)

3. It is a real time time process, “using adaptive remeshing techniques”, meaning the result can be seen immediately. (Nervous, 2014)

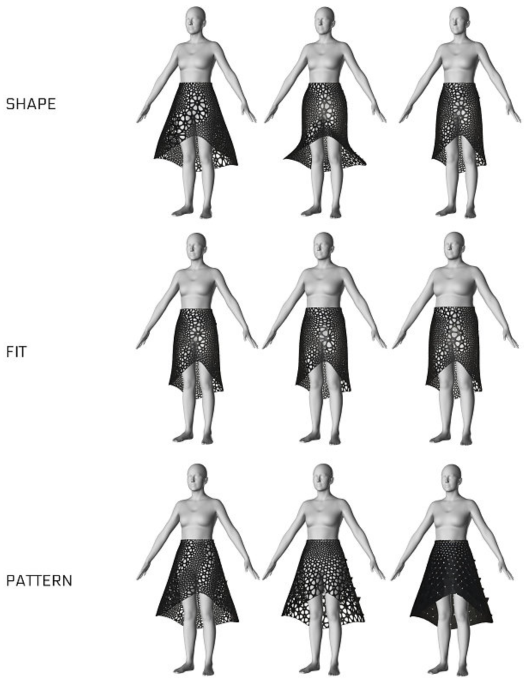


Figure 39_ Diagram of different stages of user involvement inside Kinematics Clothes app (source; System, N. (n.d.) Fit / Shape / Pattern [online]. Available from: http://n-e-r-v-o-u-s.com/projects/index.php?/albums/kinematics-cloth/content/kinematics-cloth-diagram/ (Accessed 7 October 2019).

Figure 40_Kinematics Cloth web app user interface; direct geometry manipulation with familiar elements like sliders and buttons (source; (Anon 2019. kinematics clothing app. [online] Available at: <https://n-e-r-v-o-u-s.com/kinematicsCloth/> [Accessed 26 Nov. 2019].

Kinematics Fold

Kinematics fold is an app used to make products, designed in Kinematics Clothes, 3d printable. Upon 3dprinting, final object geometry must be compressed,because garments are too large to be printed in a regular 3d printer. Its role is the simulation of how hinges behave when moving.(Figure 41) Dress can be folded in half twice, achieving 85% compression, before 3d printing production takes place. (Nervous, 2014)

Other purposes is deep interconnection with Kinematics Clothes app, meaning there is a feedback loop between these two. The benefit is that someone can see how clothes behave, move, fit, drape without ever 3d printing. (Rosenkrantz & Louis-Rosenberg, 2017)

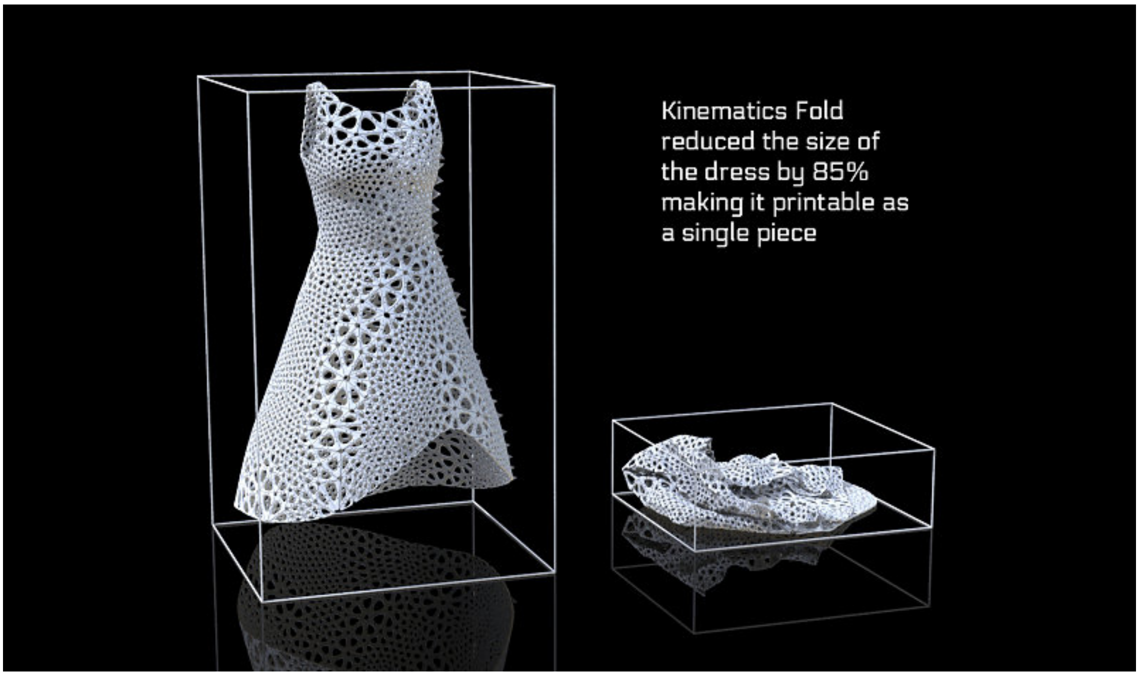


Figure 41_ Kinematics Fold simulation and size reduction (source; System, N., 2019. folded-dress354-text.jpg. [online] projects by Nervous System. Available at: <http://n-e-r-v-o-u-s.com/projects/index.php?/albums/kinematics-fold/content/folded-dress354-text/> Accessed 26 Nov. 2019)

Folding Process

The system adopts a “heuristic” method to find a minimal configuration for efficient 3d printing production, based on a rigid body simulation. Kinematics Fold folds mimics a folding process reminiscent of the way how would one fold a shirt and put it in a wardrobe. Each garment goes through a series of collision designed to reduce size in an familiar way.

Of course there are some known risks. Kinematic Fold generates a simple model version rather than complete geometry to accelerate computional process but “folding process is a fine balance between error and precision. The hinges must be manufactured to a high tolerance rate (1/10 of a millimetre) or joins solidify and start to fuse.IF the simulation is too precise, then joins experience ‘locking’ loosing flexibility”.

Nervous system formula; High error in compression, Low Error in relaxation, refitting process to make sure there is no error in hinge tolerance. (Rosenkrantz & Louis-Rosenberg, 2017)

/3.3/ Outcomes in Computational Fashon design and 3d printing

By carefully analyzing limitations of size and material properties of objects found in nature, research initially confirms the current status of additive manufacturing technologies. As such, there are several factors to be taken into consideration when 3d printing; bed size limitations and material that come with it.

At this point, research highlights multidisciplinary efforts to overcome obstacles, when it comes to 3d printing on large scale and explains how it translates back to fashion design. Furthermore it lays out an approach, based on workaround solutions found in projects concerning footwear and apparel design, where the inclusion of kinesis, perfect fit and comfort are mandatory to complement bodily movement.

In detail, there are two main directions present throughout source investigation. These are products of two different schools of thought, giving different answers to a address a common problem;

/3.3.1. Apparel design & Footwear Design; Succesful workaround solutions

First direction is characterized by materiality above all approach;
with 'parametric design' as a driving force, fashion design process is focused on combining radical production techniques with traditional craftsmanship, in order to overcome dead-ends. Successful combinations of next generation materials, along with the development of sophisticated knitting systems and later manual assembly, results in garments and shoes with unique properties when it comes to flexibility and comfort. Key projects driving the effort are UN Studio's 'Reinventing the Shoes' and Niccolo Casas and Iris van Herpen's Lucid Collection of dresses.

Second direction is characterized by 'geometry begets materiality' approach;
With generative design as a driving force, fashion design process is focused on the geometry level, with the computational construction of metamaterials, aiming to reduce space before 3d printing production stages take place. All these can be achieved through an ecosystem of web apps, designed to hande different stages of size reduction (compression, folding through simulation) to user interaction (design). Key project concerns Nervous System's 'Kinematics dress' and its ecosystem of apps

Common themes behind all projects, during current chapter are the following;

- All projects mark the sum of the collaborative effort between key disciplines, assuming roles in areas of high expertise.

- All projects are characterized by their ability to realize evolutionary steps towards integrating computational design workflows with efficient 3d printing processes.

- All projects develop mechanical systems based on hinges, joins or knitting systems in order to overcome 3d printing limitations.

- Byproduct of the collaborative effort is the creation of materials with new properties, thus enabling new territories of expression and experimentation.

With outcome of exloration in mind, following chapter covers how meta-materials enable new ways of expression with human body as an interface of experimentation.

4/ 3d Printing & advanced, behavioural materials for the body

According to previous chapters, 3d printing, along with computational design and scanning technologies, introduce a new notion of fashion design process. In that fashion designers are able to produce fashion design items perfectly tailored to the human body. Furthermore, recent advances in 3d printing, in combination with new material production tehnologies, enable the development of collaborative projects that not only adhere to the basic rules of perfect fit, but also comfort and flexibility in bodily movement. However, given that fact that byproduct of the collaborative effort is the creation of new material properties, one question remains unanswered, can we develop interactive, dynamic items with wearer's surroundings and express the body in unprecedented ways, thus heading towards the more socio-cultural nature of fashion design?

/4.1/ 3d printing & behavioral materials; Geometry begets materiality

The projects described in upcoming sections, employ a similar strategy to the one found in Nervous System's 'Kinematics' project. The approach is similar to 'geometry begets materiality'; the objective has been in finding ways to how "form" or "geometry" may incorporated inside a workflow to shape the "material" in order to achieve the desired behaviour so as to express the dynamic properties of human body. On the contrary though, the intention is not to subscribe to the logic of a conventional 'mechanical' system, comprised by moving parts, such as joins or hinges, used by Niccolo Casas and Nervous System. Upcoming projects showcase versatility in developing systems who are influenced by the behaviour of the material itself.

At this point research highlights the roles of a 'compliant' system mentioned in Behnaz Farahi's projects such as 'Caress of the gaze' and 'Ruff', an 'integumentary' system mentioned in Neri Oxman's 'Anthozoa' project and a 'micromechanical' system based on Francis Bitonti studio 'UNIQ scoliosis brace' project. While there is no emphasis on a particular order during the analysis of these projects, the goal is to cover certain systems in use and realize successful products.

/4.2/ Compliant system; motion through material behaviour

According to Behnaz Farahi, 3d printers enable printing items with dynamic behaviours, such as folding, twisting and bending with the same level of flexibility to how human body moves. Furthermore, such behaviours can be useful in order to investigate hidden, elemental forces behind human body, allowing for further investigation on its structure and its biomechanics. Throughout her projects, materiality is key; "by designing interactive compliant textiles, garments become interfaces with the wearers' surroundings". Her intentions are to achieve a "compliant" system , where motion can be achieved through material behaviour itself. In technical terms ,she describes it as a system that "adapts its form through the deflection of flexible members rather than through joints or hinges". (Farahi, 2017)

/4.2.1. Multi-material 3d printing; Project 'Caress of the Gaze'

Agenda

Focus is on dynamics of the skin, as it is the largest organ of the body and in constant motion, stimulated by internal and external forces ,by reacting to temperature and moisture, but to feelings as well. Clothing culturally behaves as a fabricated skin, changing its form and expressing social issues such as identity, gender and act as a medium with external world. (Farahi, 2015)

The product

'Caress of the gaze' is a garment that encourages interaction, it is based on multi-material 3d printing technologies, that can sense gaze and react accordingly by changing its form, effectively mimicking real skin behaviour. (Figure 42)

Geometry

Geometry is inpired by reptile skin behaviour as well as fish like quills. Garment was made possible using cellular mesh geometriess, particularly useful to showcase dynamic behaviour "such as twisting, bending, flexing."

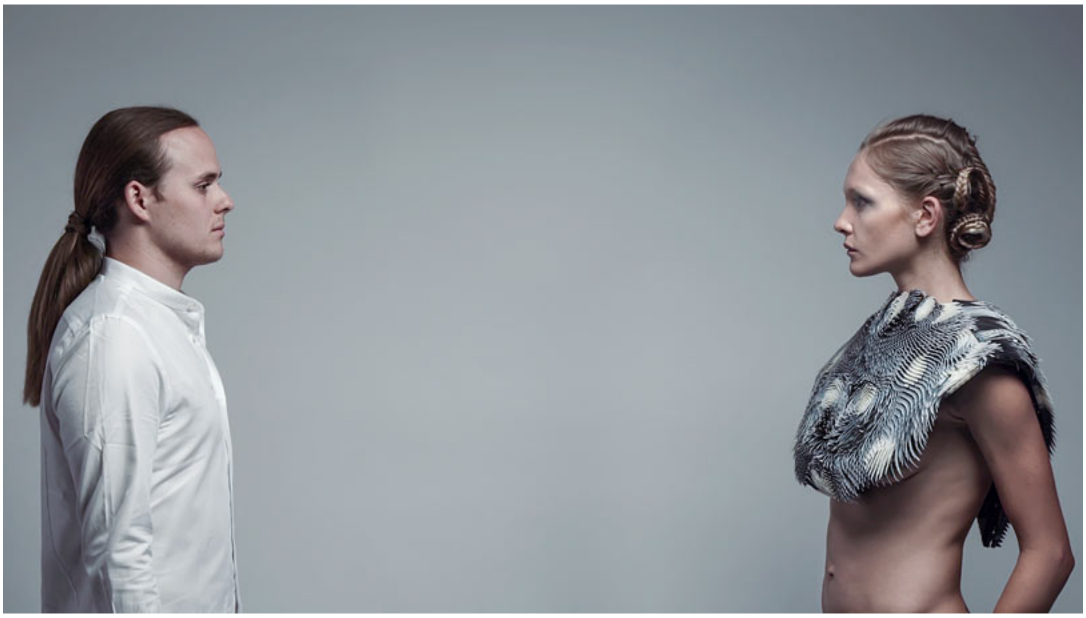


Figure 42_ 'Caress of gaze'; a multimaterial garment that can sense gaze and react. (source; Anon 2019. Behnaz Farahi. [online] Behnaz Farahi. Available at: <http://behnazfarahi.com/caress-of-the-gaze/>Accessed 26 Nov. 2019)

The cellular mesh can hold fish like quills and position them in a way so they overlap,hence create interactions. “The size of those quills as well as their rigidity/flexibility, determine the distribution of forces, while help achieve a certain aesthetic expression”. (Farahi, 2017)

<u>The process</u>

Project uses 3d printing technology that allows the fabrication of a combination of materials with different variations in flexibility/density and create materials with difference in their properties. The materials are printed on an Object500 Convex 3d printer. (Farahi, 2015)

The procedure is described as follows;

1. At first, a series of experimentations take place in order to determine an analogy between soft, flexible to stiff materials comprising the form of the garment. The black ones concern the flexible materials and

determine the flexibility of the structure, while the white ones provide with structural rigidity.

2. The outcomes of exploration from experiment form the structure of the garment.

3. The dynamic form of the garment is achieved by using an actuation system, with special shape memory materials such as Shape memory alloy, which acts as a muscles, therefore enhancing the notion of ‘artificial’ skin.

4. Last but not least, the project also investigates interactions with other people’s gaze. As a result, a depth image sensing camera (3mm diameter) is used in order to capture that gaze. (Figure 44) It is positioned underneath garment’s quils. The data from camera are sent via a microcontroller at the back end of the garment and activates a circuit of Shape Memory alloy wires that control the motion of garment. (Farahi, 2017)

Figure 43_ Analogy between soft, flexible(black) to stiff materials (white), all 3d printed in one piece (source; Anon 2019. Behnaz Farahi. [online] Behnaz Farahi. Available at: <http://behnazfarahi.com/caress-of-the-gaze/> , Accessed 26 Nov. 2019)

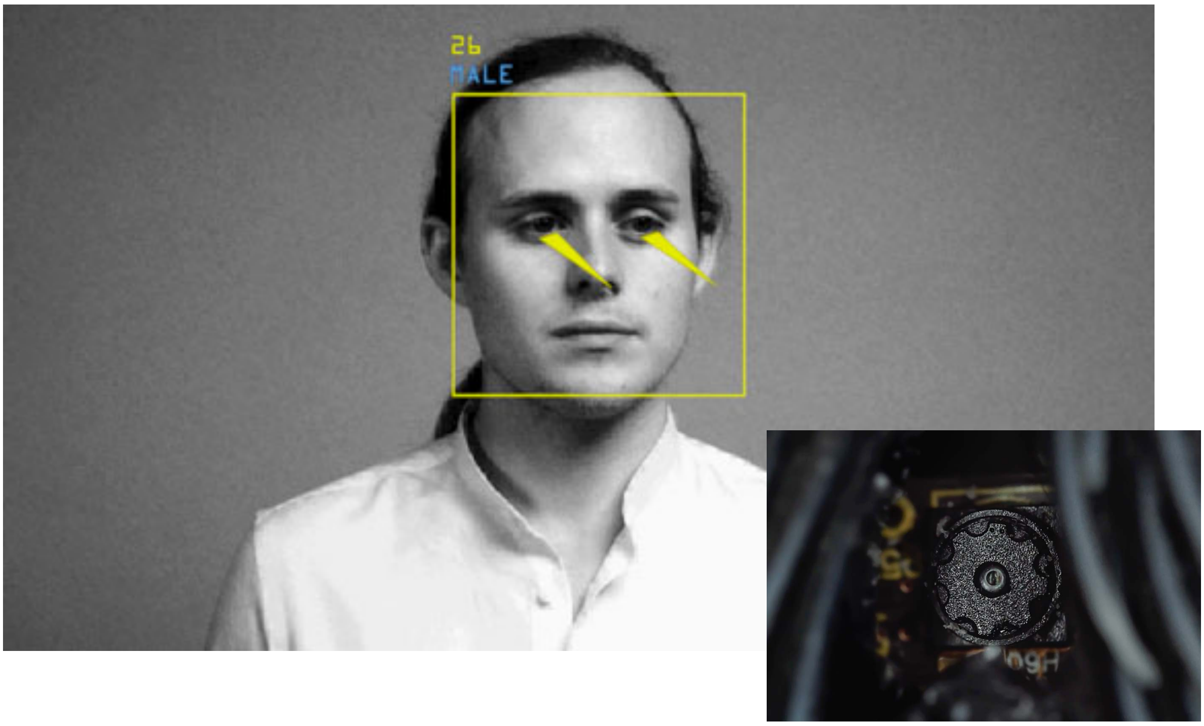


Figure 44_ A depth sensing camera behind cloth senses gaze and activates the network of SMA actuators, in order. To produce motion (Anon 2019. Behnaz Farahi. [online] Behnaz Farahi. Available at: <http://behnazfarahi.com/caress-of-the-gaze/> , Accessed 26 Nov. 2019)

/4.2.2. Materials and geometrical configuration; Project Ruff

Collaboration: Behnaz Farahi (architect, designer) – Pauline von Dongen (Fashion Designer)

Agenda

While 'Caress of the gaze' relies primarily on multi-material 3d printing in order to achieve its dynamic behaviour,project 'Ruff' is primarily focused on geometry level; it showcases that material behaviour has less to do with its properties and more with its geometrical configuration. (Farahi, 2017)

The idea is better described by science writer David Chandler who says that the "the crucial aspect of the new 3-D forms has more to do with their

Figure 45_'Ruff'; spiral form collar (source; Anon 2019. Behnaz Farahi. [online] Behnaz Farahi. Available at: <http://behnazfarahi.com/ruff/> , Accessed 26 Nov. 2019)

unusual geometrical configuration than with the material itself, which suggests that similar strong, lightweight materials could be made from a variety of materials by creating similar geometric features". (Chandler, 2017)

Geometry

Structures in the form of spring. With collar taking a form of folded coil or spiral. Inpiration is taken from a mid 16^{th} century, west European, protective folded collar. (Farahi, 2015)

The process

The project uses rigid, fragile materials create flexible structures using multi-jet modelling, with MJM 3d printing tehnology 3D Systems' ProJet 3500 HD Max printer, which prints solid plastics wrapped in wax support material. (Farahi, 2015)

The procedure is described as follows

1. By carefully selecting geometrical configuration, those rigid structures can achieve flexibility, shows material can be effectively controlled. Collar takes form of spirals, while various topology optimizations take place in order to achieve desired aesthetic expression.

2. Project confronted size constraints during 3d printing, later solved by wrapping spirals in one another.

3. Motion; SMA actuators were used for that project as well in order to achieve the motion of expansion and contraction. (Figure 46) This procedure gives the collar an organic notion, with life like behaviour. (Farahi, 2017)

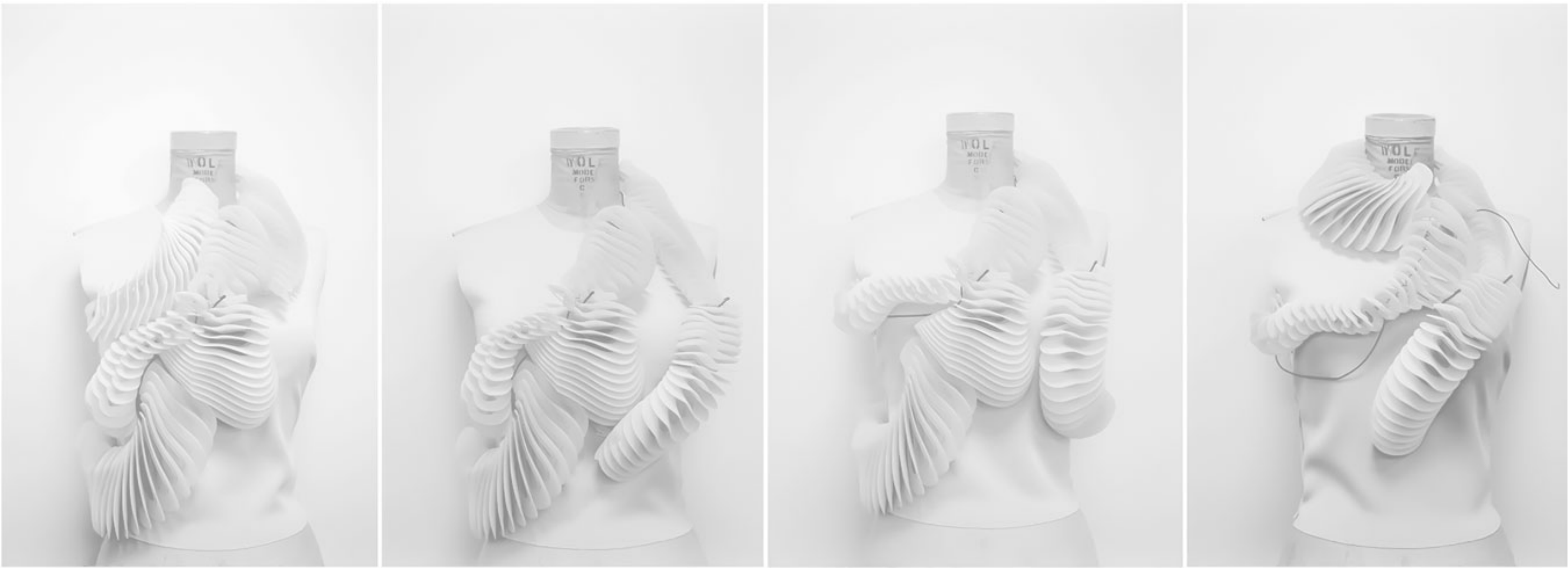


Figure 46_ SMA actuators help achieve motion of expansion and contraction (source; Anon 2019b. Behnaz Farahi. [online] Behnaz Farahi. Available at: <http://behnazfarahi.com/ruff/> [Accessed 26 Nov. 2019].

/4.3/ Integumentary system; filtration through material behaviour

According to Neri Oxman, cutting edge technologies, such as 3d printing enable fashion desgners to operate at nature's scale. Today Fashon designers hold a significant advantage "to manipulate physical properties at the size of cells, and alter them in terms of colour, stifness and conductivity, even smell". Concequently, generating fashion design items should no longer be limited to assembly of fabrics and stitching. Furthermore, 3d printing technologies are approaching resolutions close to the scale of scanning and mapping. Concequently, her intention is to design systems that effectively emulate body system and its organic functions. Part of this system concerns the 'integumentary system', the 'skeletal/muscular' system, the 'digestive' system and 'respiratory' system. (Oxman, 2017)

At this point research focuses on 'integumentary' system, with Mediated Mater Group's project ' Anthozoa'.

/4.3.1. Multi-material 3d printing; Project Anthozoa

Collaboration: Behnaz Farahi (Architect, designer) – Pauline von Dongen (Fashion Designer)

Agenda

Interest in skin as a protective and filtering mechanism. 3d printed apparel inspired by skin and its filtering mechanisms. (Figure 47)

The process

The design combines a mixture of flexible and rigid materials, within a single form 3D printed on a Stratasys' unique Objet Connex multi-material 3D printer. (Oxman, 2013)

"Waist" is comprised by soft and flexible materials, while "contours" hold more rigid materials. Form and material have been computationally defined to be ergonomic. filter successfully sweat and be aesthetically expressive. "Replace needlework with code"; no stitches or any sort of assembly and no components are alike. (Oxman, 2017)

Figure 47_'Anthozoa'; Cape & skirt, inpired by skin as a filtering mechanism (source; Oxman, N., 2019. Anthozoa: Cape & Skirt, 3-D Printed Dress in collaboration with Iris Van Herpen | by Neri Oxman. [online] Available at: <http://neri.media.mit.edu/projects/details/anthozoa> [Accessed 26 Nov. 2019].

/4.4/ Micromechanical system; improving posture through material behaviour

Studio Bitonti is preoccupied with the task of designing material systems and applications for the body. According to company's founder, Francis Bitonti, studio's intention is to create a "micromechanical" system through a series of projects aiming to "explore the organisation of matter as it relates to the mechanics of the human body at the micro scale. The aim is to create complex assemblies of soft mechanisms that both augment mechanical inputs from the body and simultaneously employ that energy to produce novel systems that result in new and unexpected material effects". (Bitonti, 2017)

/4.4.1. Micromechanical assemblies; Uniq scoliosis brace

Collaboration: Studio Bitonti– UNIQ (orthopaedic and prosthetic products)

Agenda

- Another means of expressing body in its surroundings, is by aesthetically correcting its posture with the added benefit of health
- Finding aesthetically and functionally better solutions, as opposed to current bulky braces. Those braces are used by physicians in order to deal with scoliosis problem by applying pressure at specific areas and correct spinal curvature. The reason is patients often abandon those braces due to their bulky size often resulting in expensive surgeries. (Bitonti, 2017)

The process

As of now current approach is the process of "vacuum forming medical grade plastic". Bitonti studio focuses on a much more efficient process of 3d printing a lighter form. This enables greater movement as well as comfort, all while creating an elegant package (Figure 48);

- At first, topology optimization algorithm runs through in order to reduce object mass by deleting sections with least amount of "internal stress". At this stage, designers require to input manually loads necessary to fix spinal deformation. Later they observe the forces influencing the object and conclude what sections of the object are supported and what sections need to be retained. With this procedure taken, a simple support system of a beam carrying load across both ends, which is applied by designers, ends up looking like the diagram below (Figure 49).

- Design also incorporates sensors necessary in order to measure the impact of the applied loads, carrying essential information for next generation products.

- Result is a form is based om 'michromechanical' system with an ability to help body correct its spinal issue and provide patient with the ability to breath. (Bitonti, 2017)

Figure 48_ UNIQ brace; a lightweight, stylish brace helping body to correct skeletal issues (source; Anon 2016. *3D-printed back brace offers 'fashionable' solution for scoliosis sufferers*. [online] Dezeen. Available at: <https://www.dezeen.com/2016/11/04/unyq-align-fashionable-3d-printed-back-brace-replaces-current-chunky-designs/> [Accessed 26 Nov. 2019].

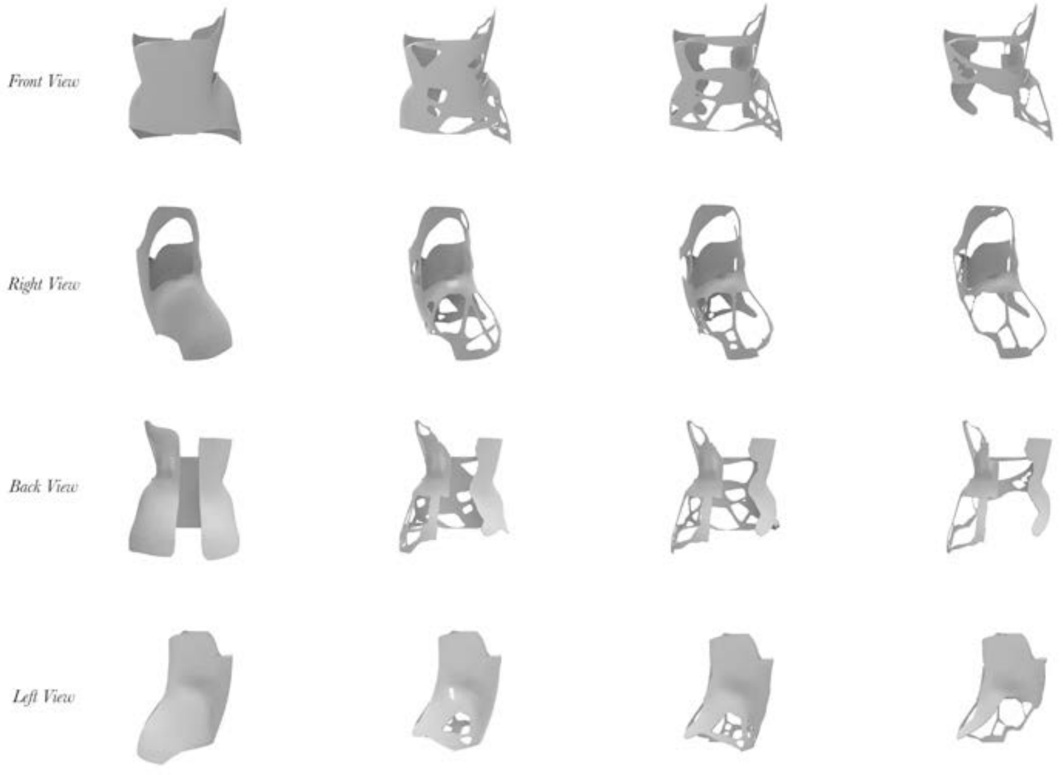


Figure 49_ Topology optimization reduces mass by erasing areas with least amount of stress, shaping the final form of the product (source; Bitonti, F., 2017. Micromechanical Assemblies and the Human Body. Architectural Design, 87(3d-Printed Body Architecture), pp. 64-69.)

Geometry

Studio is particularly studying lattices structures and find ways to improve them. In detail, these complex group of mechnisms can be manipulated in order to produce dynamic material properties that can change in each case and project. Furthermore, 3d printing also enables producing variated materials that can be 3d printed in one single piece. The result is the creation of 'intelligent' 3d materials without interrupting manufacturing workflow. The result of this study was to create a method of designing graded lattices with far bigger performance (Figure 50), by controlling deformation. (Bitonti, 2017)

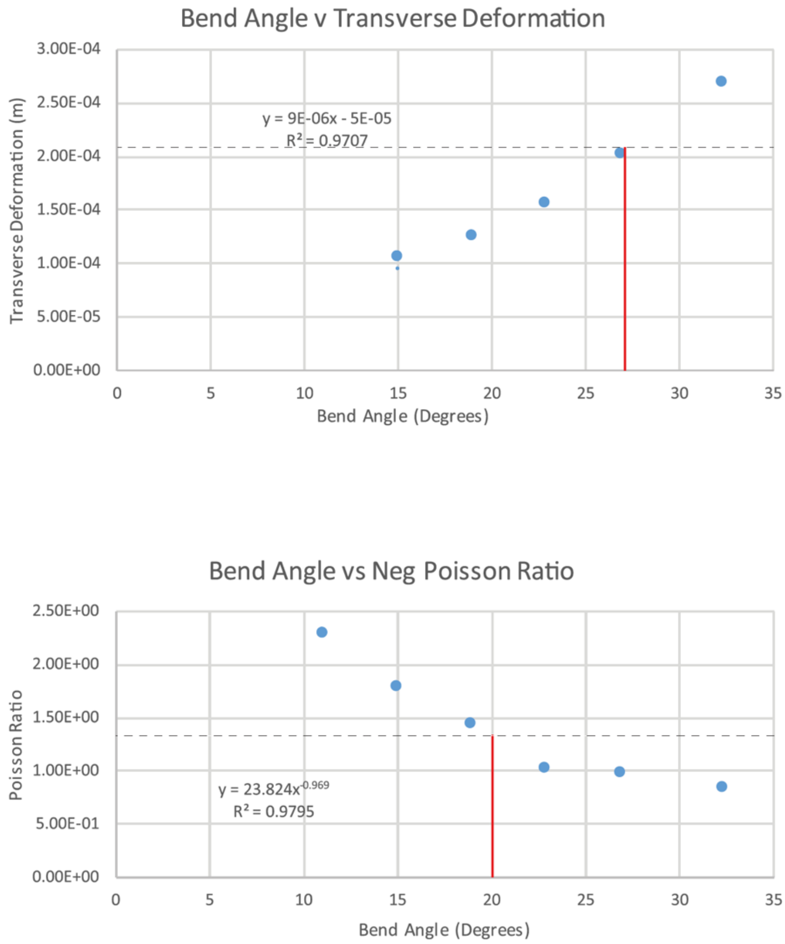


Figure 50_Studio Bitonti's newly developed graded lattices, manages bend angles of 26-27 degrees, while matching the deformation values of a uniform lattice, and a Poisson Ratio of 20-21 degrees. (source; Bitonti, F., 2017. Micromechanical Assemblies and the Hu

/4.5/ Outcomes in 3d printing & behavioural materials

Concequently there is evidence to promote the concept of ‘geometry begets materiality’ as the most current approach, in terms of realizing successful integrations between computational design workflows and efficient 3d printing processes.

What is more, there are two clear directions as part of the outcome of exploration, emerging in current chapter.

/4.5.1. 3d printing resolutions; geometry and comparative advantages

The first direction is process-driven; geometry developed through various camputational design workflows can now adapt by emulating and augmenting natural functions at the micro scale. Translating back to computational fashion design, designers as coders can now develop sophisticated systems that emulate natural ones, such as body functions and describe body motion in terms of its external surroundings. As such, fashion design process reaches towards a more socio-cultural context in general.

/4.5.2. Development of behavioural materials; geometry and peripherals

The second direction is paradigm-driven , by carefully analyzing projects and respective outcomes, research confirms that 3d printing resolutions are fast approaching the micro scales of mapping, scanning and body mechanics, thus new 3d printing technologies are introduced,such as multi-material 3d printing.

The above mentioned developments also influence the underlying role geometry plays by influencing material behaviour at the micro scale. Evidence are rich and describe abilities of geometry to alter material’s geometrical configuration in order to showcase dynamic behaviour such as motion, filtration and varying flexibility/rigidity in order to improve bad posture. Projects that concern milestones at this point are Project ‘Caress of the Gaze’, Project ‘Ruff’, Project ‘Anthozoa’ and Project ‘Uniq Scoliosis Brace’.

Thumbnails of key projects part of current chapter investigation

Finally, there is one last crucial factor to be taken into consideration, making the development of such products possible, also having prevalent position in key projects that push the narrative across research. This factor concerns the development of a ecosystem of hardware apart from software, such as scanners, sensors that track movement, cameras that capture gaze and generally equipment necessary for data input.

As such, fashion design items may no longer be limited to two dimentional assembly of fabric and stitching or developing hinges and joints as a solution to manufacture.

5/ Conclusions

<u>What is computational design, how does it influence fashion design process and how does it affect roles, disciplines and products? What does this mean for the user?</u>

During initials stages of research, a new important perspective emerges; the realization that fashion design is influenced by revolutionary computational workflows that describe the logic behind design proposal rather the form itself. An extended research based on computational designs workflows in fashion design, expands on computational design and its various forms of expression, such as 'parametric' and 'generative' design, reveal a paradigm shift towards iterative fashion design, characterized, non-linear form generation and complex, computer-generated, curvilinear geometries.

At the same time, studies on projects set user at the epicenter of this paradigm shift, when highlighting evolutionary steps of user input as the project 'Cell Cycle' introduces user manipulation in a simplified user interface, enabling various levels of engagement according to user skill level. 'Project Reverb' captures user gestures and simulates them real time, while 'Project 'Tactum' even exceeds the previous, by introducing on body manipulation.

<u>How are 3d printing technologies incorporated inside a Computational design workflow? As of now, to what extent are 3d priting processes efficient?</u>

In general, all three projects successfully produce output, in the form of ready to wear products. They also reveal efficient 3d printing processes in the form of products such as wearables and jewellery, since their size conforms to average 3d printer's bed size. Key factor enabling efficient 3d printing production concerns strategic selection of geometry in use, in order to minimize material volume, as shown from project 'Cell Cycle'.

<u>Are there any key sensibilities, limitations and byproducts when integrating computational fashion design workflows with efficient 3d printing production?</u>

At this point research identifies 3d printing limitations and expands in a wider fashion design portfolio, where sensibilities in production result in far more complexity in order to realize products, such as footwear and apparel design. These sensibilities have to do with comfort, perfect fit and flexibility in bodily movement. By carefully analyzing limitations of size and material properties of objects found in nature, research confirms the current status of additive manufacturing technologies. As such, there are several factors to be taken into consideration when 3d printing; bed size limitations and materials that come with it.

How do current 3d printing technologies perform in a wider Fashion design portfolio?

Research shows efficient 3d printing production is characterized by workaround solutions, products from two different schools of thought;

First direction is characterized by materiality above all approach;
with 'parametric design' as a driving force, fashion design process is focused on combining radical production techniques with traditional craftsmanship, in order to overcome dead-ends. Successful combinations of next generation materials, along with the development of sophisticated knitting systems and later manual assembly, results in garments and shoes with unique properties when it comes to flexibility and comfort. Key projects driving the effort are UN Studio's 'Reinventing the Shoes' and Niccolo Casas and Iris van Herpen's Lucid Collection of dresses.

Second direction is characterized by 'geometry begets materiality' approach;
With generative design as a driving force, fashion design process is focused on the geometry level, with the computational construction of metamaterials, aiming to reduce space before 3d printing production stages take place and 3d print in one piece. All these can be achieved through an ecosystem of web apps, designed to hande different stages of size reduction (compression, folding through simulation) to user interaction (design). Key project concerns Nervous System's 'Kinematics dress' and its ecosystem of apps.

Both approaches develop a mechanical system of hinges and joints in order to achieve flexibility and comfort in bodily movement.

How do various levels of integration between Computational Design and 3d printing, influence material behaviour?

Additionally, a new important perspective emerges as a result of previous outcomes of exploration; the prospect of 3d printing fashion design items in one piece and expressing far more complex properties of the body into its surroundings. Research shows evidence that promote the concept of 'geometry begets materiality', introduced by Nervous System's projects, as the most current approach, in terms of realizing successful integrations between computational design workflows and efficient 3d printing processes. This particular concept describes the ability of 'geometry' to manipulate 'material' in order to achieve the desired behaviour and express dynamic properties.

At this point research investigates systems that transcend the basic logic of a mechanical system of hinges and joints developed in Niccolo Casas's Projects and Nervous System's Project 'Kinematics'; those systems express complex properties of the body, by using geometry to alter material's geometrical configuration in order to showcase dynamic behaviour such as motion, filtration and varying flexibility/rigidity in order to improve bad posture. Projects that concern milestones at this point are Project 'Caress of the Gaze', Project 'Ruff', Project 'Anthozoa' and Project 'Uniq Scoliosis Brace'.

Key factors making them possible are;

- 3d printing resolutions are fast approaching the micro scales of mapping, scanning and body mechanics.
- new 3d printing technologies are introduced, such as multi-material 3d printing.
- development of a ecosystem of hardware apart from software, such as scanners, sensors that track movement, cameras that capture gaze and generally equipment necessary for data input.

<u>How does this translate back to fashion design?</u>

Geometry/form developed through various camputational design workflows can now adapt by emulating and augmenting natural functions at the micro scale. Translating back to computational fashion design, designers as coders can now develop sophisticated systems that emulate natural ones, such as body functions and describe body motion in terms of its external surroundings. As such, fashion design process reaches towards a more socio-cultural context in general.

Common themes behind major projects across research and diagram of integration

- All projects formulate agendas, based on strategic selection of geometry in use.

- All projects mark the sum of the collaborative effort between key disciplines, assuming roles in areas of high expertise.

- All projects rely on data input from users and the development of a ecosystem of hardware apart from software, such as scanners, sensors that track movement, cameras that capture gaze and generally equipment necessary for data input.

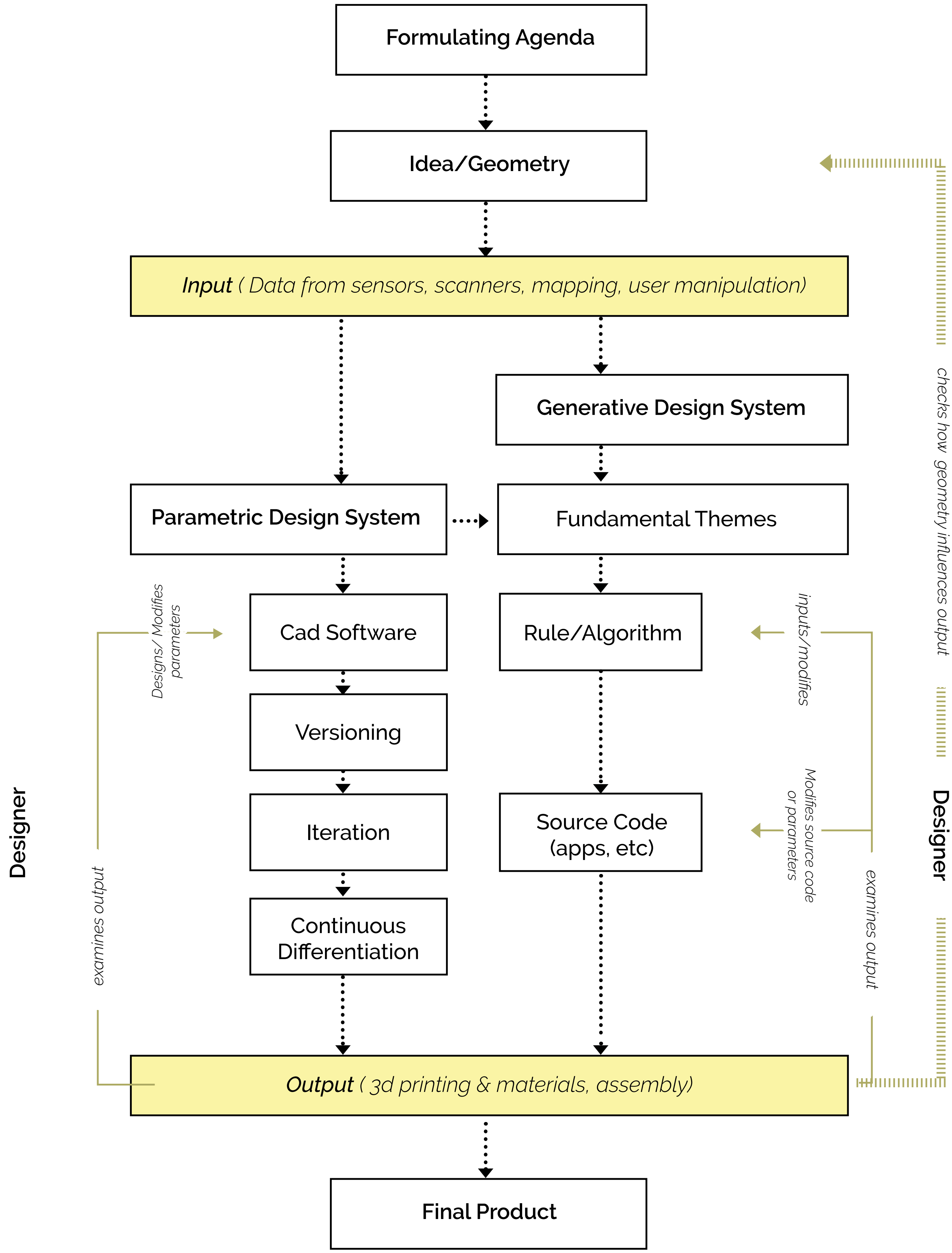
- All projects are characterized by their ability to realize evolutionary steps towards integrating computational design workflows with efficient 3d printing processes.

- Most projects develop systems in order to overcome 3d printing limitations.

- Byproduct of the collaborative effort is the creation of materials with new properties, thus enabling new territories of expression and experimentation.

With those common themes in mind, research attempts to describe a set of guidelines, outlined below;

Table 3_ (below) Diagram showcasing successful integrations between computational design workflows and 3d printing technologies, as shown from projects


Formulating Agenda
Idea/Geometry
Input (Data from sensors, scanners, mapping, user manipulation)
Generative Design System
Parametric Design System
Fundamental Themes
Cad Software
Rule/Algorithm
Versioning
Iteration
Source Code (apps, etc)
Continuous Differentiation
Output (3d printing & materials, assembly)
Final Product
Designer
Designs/ Modifies parameters
examines output
Designer
checks how geometry influences output
inputs/modifies
Modifies source code or parameters
examines output

The diagram outlined above, proposes a new workflow based on common themes across major projects and sources, subjects of research investigation. As seen from projects, collaboration team or designers. initially formulate an agenda of inspiration, facts and insight which is later translated to ideas of strategic geomeotry in use. Furthermore, they enstablish an ecosystem of hardware that inputs data, while user assumes an active role in providing information. At this point, collaboration team/designers incorporate either a parametric design system or a generative design system in their workflow.

In case of a parametric design workflow, collaboration teams/designers explore all fundamentals themes of a parametric design (such as versioning, iteration and continuous differentiation) using enstablished Cad software. Finally they examine the output in the form of a 3d printed product,either 3d printed in one piece or later assembled from parts together. In case of unwanted results, collaboration team/designers may reenstablish parameters by designing anew.

On the other hand, inside a generative design workflow, collaboration teams/designers explore geometry, characterized by fundamental themes (including parametric design) translated from rules/algorithms into apps. In a rather similar manner, they examine the output, and later input or modify rules/algorithms and let source code explore all possible permutations, producing a variety of results.

Finally, in both cases, process goes through a feedback loop between the system and a collaborative team/designer, meaning they can alter or modify as many times as possible. Output also concerns a combination of finalized geometry and strategic selection of 3d printing tehnologies in use, as well as material properties that come with it. In case of an output offering impractical results, teams or designers may check geometry and compatibility.

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Appendix

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