

# MAKING GESTURES:

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Design and fabrication through real time human computer interaction

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By:

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Submitted to the  
Department of Architecture in partial  
fulfillment of the requirements for  
the **Degree of Master of Science in  
Architecture Studies**

at the

**MASSACHUSETTS  
INSTITUTE OF  
TECHNOLOGY**

June 2015

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*“What you see and what you do belongs only to you - it’s always your own work. There’s something new and original every time you look, and who knows, the results may be spectacular”*

*Stiny, 2006, p.386*

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## **Abstract**

Design is “something that we do” that is related to our unique human condition as creative individuals, so as “making” is related to how we manifest and impress that uniqueness into our surrounding environment. Nonetheless, the use of technology in architectural design, by being focused mainly on the representation -both digital and physical - of a pre-determined idea, has neglected using digital tools in a more exploratory way by integrating body and senses in the design processes.

As physical modeling, gestures, and tools are mechanisms by which designers learn and think, I assert that creativity emerges in the very moment of impression of the self onto the material world as an improvised choreography between humans and objects -materials and tools- by using body gestures neither as action nor perception, but as the unity of both. If we are to extend our creativity and enhance the design experience through the use of digital tools, we need to reformulate the way we interact with computers and fabrication machines, by developing new models and strategies focused on the integration between both. In this thesis, I propose an alternative way for designers to use digital tools, transcending from a model of ‘operation’ to a model of ‘interaction’.

My hypothesis is that real-time interaction between designers and fabrication machines can augment our creativity and cognition engaging exploration, speculation and improvisation of designs through the use of gestures and interactive computation.

I propose a model of interaction that seeks to transcend the ‘*hylomorphic*’ model imperative in today’s architectural design practice to a more reciprocal form of computational making. To do so, I propose the Making Gestures project, which explores real-time interaction between mind, body, and tools by using body gestures and imbuing fabrication machines with behavior in order to establish a dialog, which embraces ambiguity and the unexpected to engage the designer into insightful design processes.



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Terry Knight for her support, guidance and constant motivation as my advisor. She was the fundamental support and inspiration to pursue the objectives and answers I had before coming to MIT. Your insightful, sharp and assertive critic made possible the development of this thesis.

To George Stiny, for the inspiration and insightful moments during the pro seminar sessions where the high level of discussion was a fundamental scenario to develop the main ideas of this research.

To Onur Yuce Gun, a true role model, inspiration and friend. Your support has been crucial to go on, have faith and push myself beyond my limits. I owe you my gratitude for a lifetime and beyond.

To Michael Kirschner, for the endless coffee breaks and insightful conversations about our theses. Thanks for teaching me so much and having confidence in my work.

To Victor Leung, for being an amazing and generous friend, thanks for all the moments shared, you also taught me so much. You are and will be always an inspiration.

To the reading group, a unique place where I was able to find many answers to my interests and inspiration through the highest level of academic discussion.

Thanks to Asli, Dina, Theodora, Inés, Moa, Merav, Dimitris, Katya, Athina, Daniel, Julia and the rest of the Design and Computation group for being always supportive and making me feel like home.

Thanks to my friends in the SMArchS room, Allison, Chaewon, Agustina, Gabriel and the rest, for all the amazing moments during the past two years.

To Sergio Araya, Alexandros Tsamis and the Design Lab UAI, for the support, and confidence in my work

To my parents, Fernando and Rosalía, my sister Macarena and Silverio, your love is all to me.

Finally , I would like to thank and dedicate this thesis to Ximena, my love, wife and partner in life, your daily support , love and energy, was the fuel to fight everyday and make this possible. I owe you my life, I love you.

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## Acknowledgments





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## Table of Contents

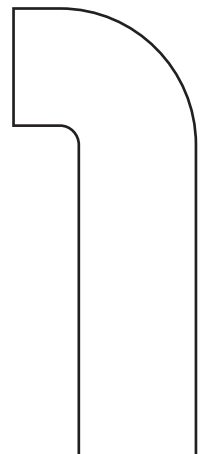
<b>1</b>	<b>Introduction</b>	page
1.1	What	12
1.2	Why	14
1.3	Background and precedents	15
1.4	How	15
<b>2</b>	<b>Background</b>	19
2.1	The Beginning of CAD era and HCI in design	21
2.2	Digital design revolution?	30
2.3	Design through technology: three problems	33
2.3.1	Design through the black-box	33
2.3.2	Design through the generic	34
2.3.3	The creative gap	35
2.4	From operation to Interaction	36
<b>3</b>	<b>Human-Tool Interaction</b>	39
3.1	Tools for representation vs. tools for creativity	40
3.2	Interacting with the surrounding environment: tools and hands as cognitive artifacts	42
3.3	Design as an embodied activity	44
3.4	Robotic calligraphy: operating vs interacting	45
<b>4</b>	<b>Making Gestures</b>	55
4.1	Project overview	56
4.2	The middle ground: human + machines	59
4.3	Why gestures?	60
4.4	Why gestural machines?	66
4.5	Towards a model of interaction: 3 approaches	68
4.5.1	Gestural interaction	70
4.5.2	Tangible interaction	74
4.5.3	Collaborative interaction	75
4.5.4	Conclusions about the experiments	77

4.6	Making Gestures: An interactive fabrication machine	78
4.6.1	Hardware and software components	79
4.6.2	How the machine works	82
4.6.3	Experiments	87
4.6.4	Free exploration and adjustment phase	88
4.6.4	Experiment findings	98
<b>5</b>	<b>Conclusions</b>	99
5.1	Conclusions	100
5.2	Contributions	102
5.2	Future work	103
<b>6</b>	<b>References</b>	106
<b>7</b>	<b>Figures</b>	108
<b>8</b>	<b>Appendix A</b>	112
	<b>Appendix B</b>	114

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# INTRODUCTION

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## 1.1 What

Design is “something that we do” that is related to our unique human condition as creative individuals, so as “making” is related to how we manifest and impress that uniqueness into our surrounding environment. In this thesis, I propose a model of interaction that seeks to transcend the *hylomorphic* model imperative in today’s architectural design practice to a more reciprocal form of computational making. To do so, I reconcile design and making by exploring real-time interaction between mind, body, and digital tools. Furthermore, by using body gestures and imbuing fabrication machines with behavior, my goal is to establish an interaction which embraces ambiguity and the unexpected engaging the designer into more improvisational and insightful design processes.

The early CAD implementations during the 1960, were based upon the beliefs and aspirations of using computers as informed, intelligent and cognitive machines. Moreover, influenced by cybernetic theories and artificial intelligence, CAD proponents intended to augment the design enterprise in terms of creativity. To do so, they sought the implementation of interactive intelligent systems as ‘creative enhancers’ able to help designers to concentrate on the creative part of the design process by suggesting design options and taking care of tedious tasks such as project documentation, organization and elaboration of quantity takeoffs. Nonetheless, despite the constant efforts of early CAD proponents to frame design into a representational and generic model for production, soon found themselves in contradiction to aspects of the creative process that cannot be codified as a meta-algorithm. Furthermore, it was a general conclusion that design was not an enterprise related to automated information processes or translating the analog into digital but one related to a much more complex problem, which was hard to define as a set of static rules and symbolic representations. As a result, the design augmentation enterprise through technology failed, orienting the use of digital tools toward areas more related to the documentation, analysis and optimization of designs establishing a clear separation between design-ideation- and representation-making.

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I start by identifying central problem of this thesis in relation to the design and representation dichotomy. The use of technology in architectural design, by being focused mainly on the representation and later optimization -both digital and physical- of a predetermined idea, has neglected using digital tools in a more exploratory way encouraging creativity by integrating the senses -perception- and body -action- into the design process. This has led to -after more than 50 years of CAD invention- the design-making dichotomy emerged from the early CAD implementations to become more evident.

Furthermore, this dichotomy has led to a disembodied design practice in which the architect is permanently performing a set of translations - from idea to, 3d Model to , code to, machine to, material- that eliminates the performative aspect of improvisation in the design process. This constant translation between representation stages, has provoked the emergence of three fundamental problems addressed in this thesis in relation to the use of digital design tools. These problems are: **a) designing through opaque technologies**, in which most of the operations are black boxed to the architect, **b) the creative gap** that exists in the translation from idea to prototype, and finally **c) the impression of the 'unique' through 'the generic'** as embedded operations both in software and hardware.

Moreover, as physical modeling, gestures, and tools are mechanisms by which designers learn and think, I argue that in order solve these problems and to extend our creativity enhancing the design experience through the use of technology, we need to reformulate the way we interact with it by moving towards interactive design and fabrication processes. Hence, I assert that creativity emerges in the very moment of impression of the self onto the material world as an improvised choreography between humans and objects -materials and tools- by using body gestures neither as action nor perception, but as the unity of both.

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## 1.2 Why

My Hypothesis in this thesis is that real-time interaction between designers and fabrication machines can augment our creativity and cognition engaging exploration, speculation, improvisation and knowledge production about designs processes through the use of gestures and interactive computation.

In the case of designers, architects, and artists, tools are part of a repertoire of cognitive, symbolic, and semiotic artifacts with which each explores and learn about design problems. The use of digital design tools currently relies upon a model of 'tool operation' in which a designer typically pauses in order to produce a digital or physical representation of an idea. Furthermore, in separating designing and prototyping from the development of an idea when working in a digital environment -with a mouse or keyboard- the acts of making and learning through exploration disappear. A designer cannot touch, feel or interact directly with the objects he creates; this moment of sensing, feeling and discovery is lost.

Therefore, the main problem this thesis addresses is the one related to the one-way communication -clicking and typing- established between human and machine at the different stages of the design process -from mind to software, from software to code and from code to material- which constrains the space for exploration, learning, and knowledge elicited about designs by neglecting the use of tools as 'objects to sense' and 'to think with.'

The main contribution to the design and computation field is the one related to the creation of an interaction model that takes into account the development of a framework for action through gestures and machine behavior, in contrast to one focused on the representation of plans for action. Through this thesis I contribute to the field of design and computation by reconciling design and making changing the current paradigm present in digital design processes that relies heavily on 'disembodied tool operation' to a more fluid form of computational making based on 'embodied tool interaction'.

As precedents, first I discuss early adoptions of technology in design by contrasting the most technical approaches vs. the ideological and more experimental implementations of CAD. To do so, I revisit different projects and their approach to Human Computer Interaction in design through cybernetics and Artificial intelligence. Furthermore, I analyze the massive introduction of CAD-CAM systems in Architecture, and the main perspectives related to the use of computers in design by presenting the theoretical perspectives, assumptions and later disappointments related to the use of digital tools as “creativity enhancers.”

I then draw upon cognitive science and philosophical theories that suggest from an enactive perspective a critic to the current model of interaction with tools towards a body centric approach to engage cognition and creativity through material interactions instead of external and visual representations. By this discussion I aim to demonstrate why gestures and the use of gestural machines are crucial aspects to consider in order to promote creativity and originality through improvisation.

This thesis proposes an alternative way of using with machines embracing aspects of embodied interaction, behavior and communication between designers and machines. To do so, I use gestures, tangible interfaces and Artificial intelligence to engage a more reciprocal way of making by the establishment of a conversation instead a mere communication from creator to executor of a predefined plan. In other words, this thesis proposes a platform for interaction between humans and machines focusing in the exploratory aspects of design embracing aspects of improvisation, ambiguity, impression and discovery in the development of an idea.

Through the course of this thesis, I implement 3 forms of human machine interaction focusing on the different aspects of the process in terms of inputs and outputs between the actors involved. Moreover, these models of interaction and their implementations

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### **1.3- Background and precedents**

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### **1.4 How**

are the base to formulate and determine the characteristics of an interactive fabrication system that promotes improvisation and exploration in real time.

The final project is implemented as interactive fabrication machine for the fabrication of styrofoam prototypes to foster design and material exploration through the use of machines. The goal of the project implementation as an interactive machine, is to prove that creativity emerges in the very moment of impression of the self onto the material world as an improvised choreography between humans and objects (materials and tools) by using body gestures neither as action nor perception, but as the unity of both in order to solve the problems addressed by this research.







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**BACKGROUND**

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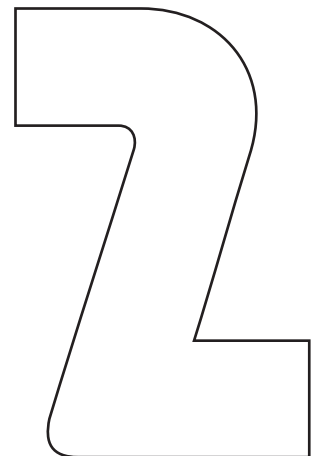


Fig. 1  
Sketchpad: a man-  
machine graphical  
communication system



In the beginning of the CAD era, Human-Computer Interaction became a central topic for many researchers, who under the paradigm of Artificial Intelligence, sought the development of new intelligent systems and interfaces to complement and augment the design enterprise. According to Bazjanac (1975), the use of the computer as a tool for design was taken on consideration by many architects mainly because of the “sweet promises” made by the upholders of Computer Aided Design, which claimed that computers would “free” designers from distracting and tedious activities to allow them to spend more time in the design itself. Furthermore, the use of computer-aided models would help designers to predict performance of designs and also accumulate experience and knowledge from the designer (Fig. 1), which could be available anytime for new projects (p. 17).

Nonetheless, many of these promises made during the 1960s turned into disappointment and skepticism from early adopters of these technologies after some years, mainly because they realized that this type of intelligent design system was based on assumptions and hypothetical models translated from the engineering to the architectural world. In addition, while first computer-engineering models were based on procedures and rules that had to deal with numbers and mainly data processing to find a solution, the computer-architectural model had to deal

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## **2.1 The beginning of CAD era and HCI in design**

Fig. 2  
The architecture  
Machine Group



with aspects of uncertainty and creativity very difficult to describe explicitly. As Milne (1975) asserts, this moment of innovation “can be described as sudden and apparently spontaneous reorganization of previously dissimilar elements into an integrated whole, which the designer believes is different from everything else he has known before”(p. 33).

In “Reflections on computer aids to design and Architecture,” a collection of writings about the first decade of CAD (Negroponte, 1975), it is clear that beyond implementation limitations such as high cost of equipment or the lack of more advanced technologies, the overall claim was that computers were not being used in augmenting the design process but instead in mechanical, structural and accounting tasks (Negroponte, p. 7).

In addition to the lack of technology, many of the disappointments that emerged from this type of concerns, were also related to the incorrect assumption that design was some sort of information processing task (Milne, 1975, p. 32). Moreover, because computers were fast and efficient in information processing tasks, many of

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the promises of the early CAD implementations were focused on augmenting the design process by helping designers with these kinds of tedious tasks such as documentation, project organization or quantity take-offs.

Furthermore, the idealization of the computer as an equivalent to the human brain and the anthropomorphization of the computer as a partner or surrogate (Negroponte, 1975) was present in many of the projects developed in the first CAD era (Fig.2). As a consequence, this led after many years to disappointments in relation to how current technologies were insufficient to fulfill the early promises or goals proposed by his authors (Negroponte, 1975, p. 6). The predictions of computers as machines that in the future would surpass the limits of human intelligence and creativity were rapidly replaced by the mere hope in future developments in the area of artificial intelligence that would make the enterprise of augmented design through computers possible.

Some conclusions, according to many authors in the book, were that

many of the early promises of CAD were based on representational models of an idealized and mechanized intelligence (Fig.3) inspired by AI leaders such as Minsky, Papert, Pask and Selfridge that was impossible to achieve at that time (Negroponte, 1975, p. 7). According to Coons (1975), “the creation of an idea or a design or an invention is really a learning process”(p. 28) that is, by introspection, experience and association of ideas (p. 28). Moreover, the designer has to “teach himself, and this process cannot be traced explicitly even in retrospect”(p. 28). Thus, the idea of this super intelligence or meta-algorithm to create processes for design was at the moment already known as impossible despite the efforts for constructing these kind of heuristics (p. 28).

Despite the shortcomings and difficulties identified in the first years of CAD implementations, the idea of design as a creative and cognitive process was present in many of the author’s contributions to Negroponte’s book. The concept of design as a process by which “innovation” emerges (Milne, 1975, p. 32), had more relation to a problem of interface between designer and machine that somehow was obscured or pushed aside by the optimistic and misleading promises of CAD proponents and the constant effort to frame design as a set of mechanical procedures and rules. Many of the most successful implementations of CAD related to design and creativity presented in Negroponte’s book were the ones related to projects focused in the communication between designer and machine through bodily and perceptual engagement with the designs produced.

As an example, HUNCH was a project developed by James Taggart inside the Architecture Machine Group at MIT, which was a computational tool that engaged a form of interaction in which the system integrated the creative power of the designer with the computational power of the computer. Negroponte (1975b) writes, “... faithfully records wobbly lines and crooked corners in anticipation of drawing high-level inferences about...! The goal of HUNCH is to allow a user to be as graphically freewheeling,



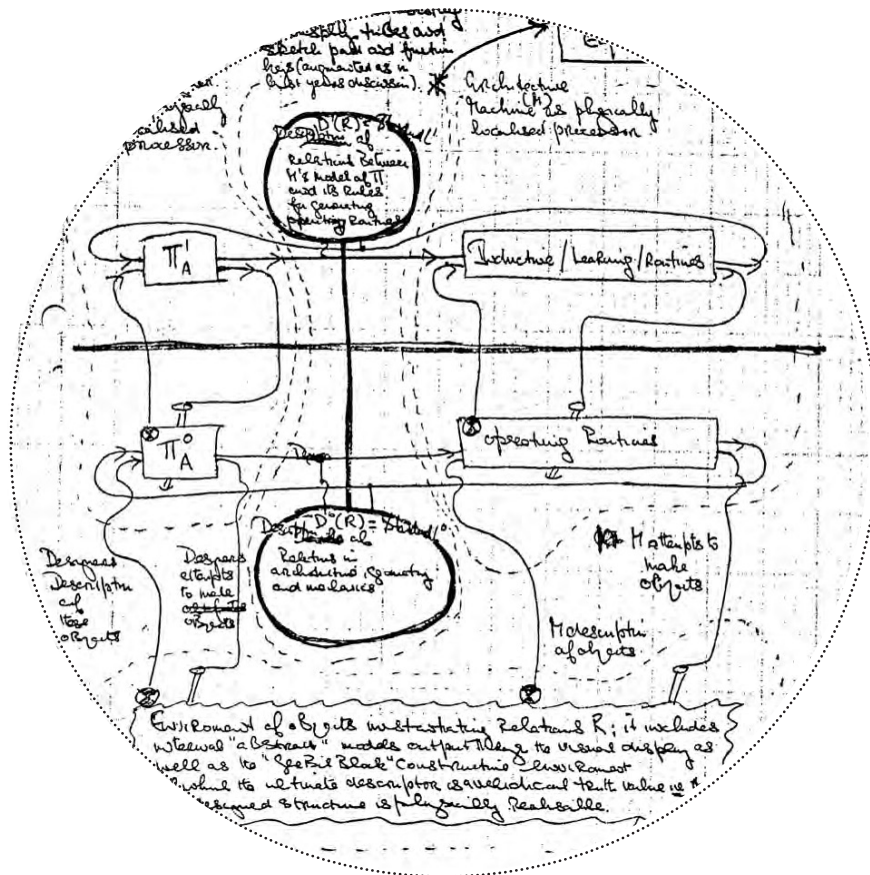


Fig. 3

Pask Gordon. Aspects of Machine Intelligence

equivocal, and inaccurate as he would be with a human partner; thus the system is compatible with any degree of formalization of the user's own idea" (p. 65). Moreover, the system used a stylus (fig in next page) as input device, which captured sketching from the user and transformed this input in a digital visual representation (lines or points). The computer interpreted user's input and returned a shape that corresponded to initial creative intentions of the designer. The logic of the project was based on the combination of the creative power of the designer and the processing power of the computer to store information and process it at a higher level to propose alternatives to design intentions.

Fig. 4

HUNCH, using the  
Applicon 800 system



Moreover, to ARCHMAC -following Gordon Pask's Work on conversational theory- HUNCH (Fig. 4) was the opportunity to take a substantial leap in the development of Interactive Graphics by focusing in "graphical abstractions and nebulous interactions commonly found in human discourse accompanied by graphics"(Negroponte, 1975). The main goal of the project was to use computer vision as an inference-making behavior machine to interact with the designer by grasping "intention" using models of interpretation of the agents involved in the conversation(Fig 5-6). Negroponte was specially assertive in identifying one key problem of this type of project that was the imposition of a system that try to leave aside important aspects which are intrinsic of human beings such as 'error' ,`imprecision´ , intentions and the myriad of interpretations and meanings of those intentions.

Nonetheless, according to Sutherland (1975), the major shortcoming in the early implementations of interactive digital tools such as SKETCHPAD and HUNCH was one related to the antithetical nature of human brain and the computer. Moreover, it was clear that beside the apparent freedom delivered by the



Fig. 5

HUNCH using the  
Sylvania Tablet

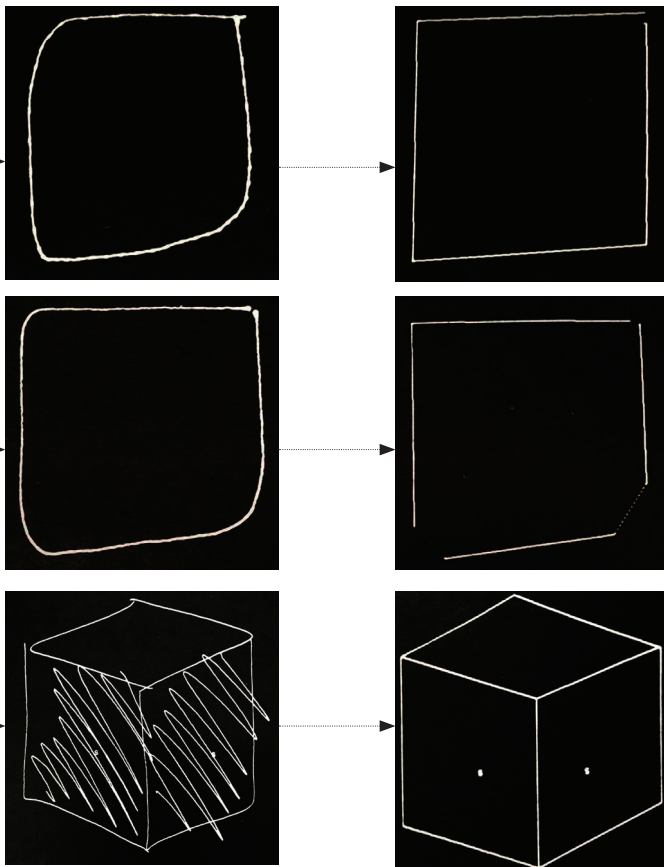
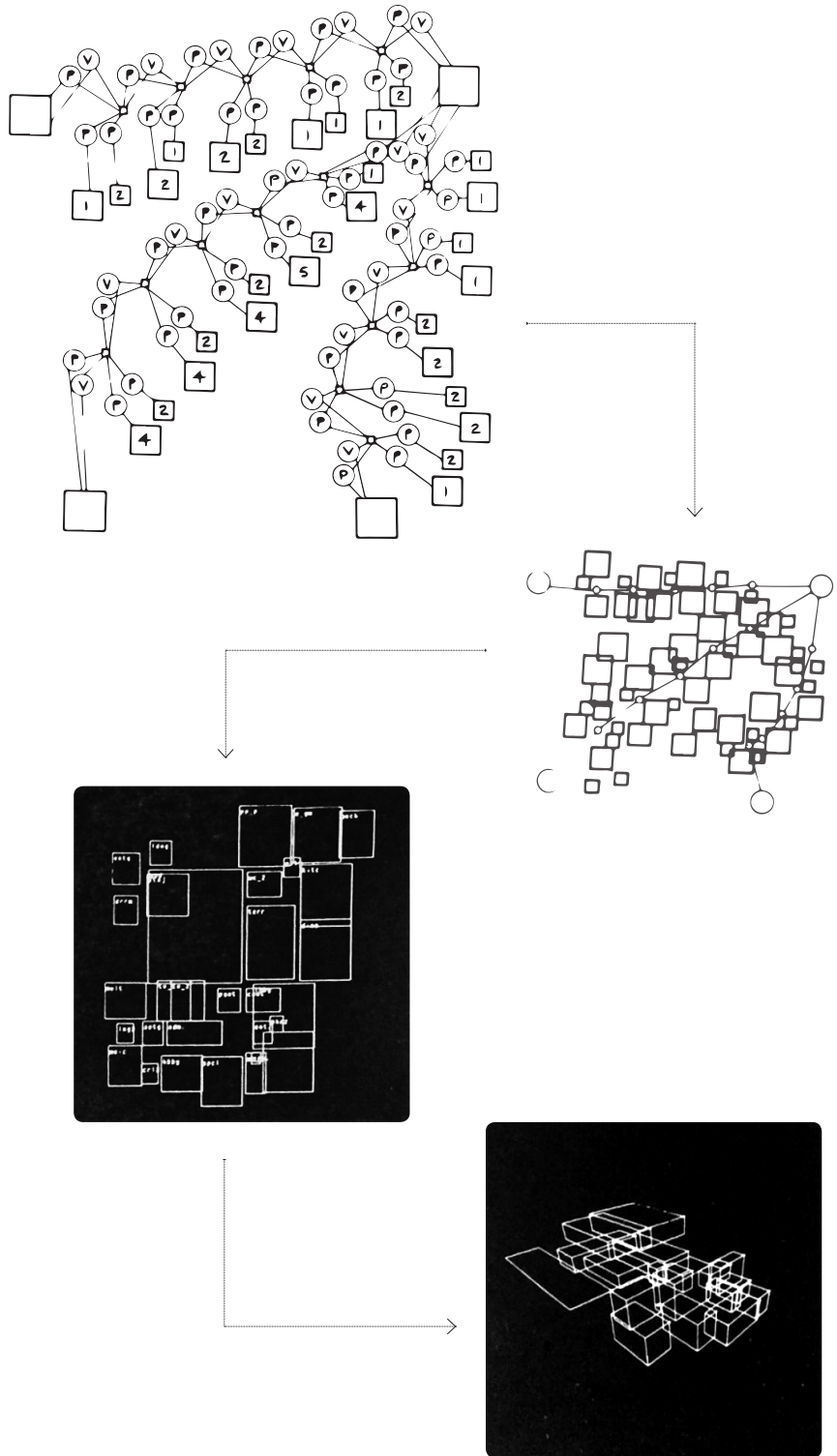


Fig 6

Sketch Recognition  
and Interpretation by  
HUNCH

Fig 7  
From diagram to  
architectural Layout.  
ARCHMAC



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interaction between designer and machine to produce a drawing, “an ordinary draftsman is unconcerned with the structure of his drawing material... is concerned principally with the drawings as a representation of the evolving design”. Furthermore, Sutherland asserts that the outcomes from SKETCHPAD were something totally different from what was expected from a computer-produced drawing, which “is dependent upon the topological and geometric structure built up in the computer memory as a result of drawing operations”(p. 75). It was clear to Sutherland, and later to Negroponte and Taggart, that a computational approach to design in terms of ‘augmentation by automation’ was difficult to implement because of the differences between the constant evolving logic of the human brain and the structured logic of the computer that demonstrated its incapability to grasp the designer’s intentions.

One interesting conclusion about the early implementations of technology in design is that many of the promises were based upon the beliefs and aspirations of computers as cognitive machines, which by the implementation of artificial intelligence would augment the design process. Nonetheless, the constant efforts of early CAD proponents to frame design into a representational and generic model for production(Fig. 7), soon found themselves in contradiction to aspects of the creative process that cannot be codified as a meta-algorithm. Furthermore, it was a general conclusion that design was not an enterprise related to automated information processes or translating the analog into digital but one related to a much more complex problem, which are hard to define as a set of static rules and symbolic representations.

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## 2.2 Digital design revolution?

More than 40 years after the first CAD implementations, many of the questions emerged from the implementation of computers in design, which have been discussed over the past decade, still remain as major concerns in the design field. Furthermore, the discourse of digital design during the 1990s was framed by a blending of theoretical, philosophical, methodological, technical and professional origin (Oxman, 2006, p.236.). As Kolarevic (2003) asserted, “digital technologies are changing architectural practices in ways that few were able to anticipate just a decade ago”(p. 3). This optimistic perspective about the future of the architecture and design, which can be related to the promises and aspirations of technological improvements expected by early CAD adopters, was oriented towards an initial understanding of the geometrical possibilities and limits of digital tools in terms of experimentation and research of geometries.

Nonetheless, the fascination for new forms of representation and the emergence of novel geometries didn't overcome the initial concerns related to design augmentation in terms of creativity. In addition, the optimistic perspective of proponents of this new digital paradigm replaced the concerns and disappointments of the 1970s. In addition, by borrowing technology from aeronautic and automotive industries, architects started talking about a “digital continuum”(Kolarevic, 2003, p. 3) from design to construction by which architects finally were able to expand the boundaries of architecture to unimagined limits. Moreover, thorough CAD-CAM processes, architects were able to surpass the limits of the digital into the realm of the physical.

Nonetheless, many of the assumptions and breakthroughs derived from the digital revolution in design and architecture since the 1990s focused on formal concerns (What can I design with a computer?) and later the materialization of those forms (How can I build it?). Hence, one question that remains unanswered is how can designers interact with current technologies to design in a



more creative way and not only represent or build them in a more efficient way?

Under the paradigm of information-driven processes, the concerns related to creativity through technology were justified through emergent systems derived from the use of algorithmic logics and parameterization of the architectural form and its relations with the environment through data and recently by the advances in CAM Processes (Fig 8). Moreover, many questions related to design augmentation through technology and how designers could interact with machines to generate better designs using technology has been obscured. As Andrews (2010) asserts, parametric design is shielded by rhetorical structures to defend the lack of a mature discourse about space and design (p. 137). Moreover, Andrew argues, that because of the “lack of attention to contemporary developments in the modeling of the relations between individuals and their environments”(p. 151), the parametric paradigm is in crisis. The current model of “digital design” relies on processes based on representations that respond only to its inner logics and fixed structures with only apparent flexibility.

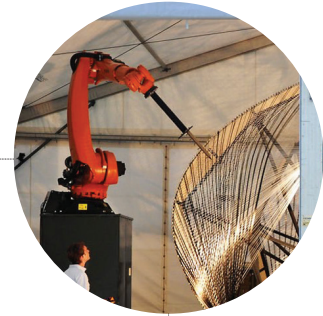


Fig 8

Fig 9  
Generic designs



Furthermore, it is clear that after more than 50 years of the emergence of CAD, the goal of design augmentation was never accomplished in the way its proponents intended to. Moreover, it is possible to argue that the main use of digital tools for design is the one focused on the production stages of a design. At the same time, it is valid to assert that the more “experimental” group of digital practitioners is shielded under a discursive rhetoric about complexity, artificial intelligence and behavior based on symbolic and disembodied representational procedures, which show only combinatorial emergent behaviors, but little or absolute no feedback with the designer in relation to creativity and cognition (Fig. 9) which in the end produced a myriad of generic applications of the same procedures at different scales.



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Current use of digital tools, by being focus in the representational aspects of a design, in the transition from mind to - model to - code to- machine to - material it is possible to identify three fundamental problems about the use of technology into the digital design process. The first one is the problem of **black-boxed** processes embedded into software and machines that might bias the design processes into more representational efforts instead of the creative/cognitive aspects of design process. From this black-box concept it is possible to identify the other two problems. One is related to the use of **generic operations** - embedded into software and hardware- to impress a specific and non-generic design idea. The final one, is related to the '**creative gap**' that occurs as a result of the use of black-boxed generic operations in the mentioned transition from design idea to the fabrication of the prototype.

As discussed in the previous chapter, from the beginning of CAD, the concerns about the relationship between humans and technology in design were based upon the assumptions of a symmetrical symbiosis between human and machine. Moreover, the development of "intelligent" tools as "creative enhancers" was an enterprise that failed because of the naive assumptions of the human mind as an information processing machine and the simplistic view of human skill and expertise (Dreyfuss, 1986, p.12) that could be translated to combinatorial and discrete operations of data processing and analysis. Furthermore, it is valid to assert that current use of digital tools somehow maintain this assumption by leaving 'the human' out of important and crucial moments of the process of the physical manifestation of an idea, leaving the "tedious and time consuming tasks" such as drafting or calculating tool paths in a CAM software inside the computer as black-boxed opaque operations to the designer.

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## 2.3 Design and technology: three problems.

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### 2.3.1 Design through the black-box.

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### 2.3.2 Designing through the generic

If we consider that design is “something that we do” which is related to our unique human condition as creative individuals, one can argue that **“design and making” is related to how we manifest and impress that uniqueness into our surrounding environment.** Hence, it is valid to assert that after more than 50 years of CAD invention the possibility to impress that uniqueness through the use of software and digital fabrication machines is limited. Moreover, because the machine is the one that determines the way something will be made according to predetermined structured procedures, the actual process of making, exploring and having feedback through seeing and doing is lost.

Hence, **why should designers accept that the physical manifestation of our ideas should be processed and expressed through this black-box using generic operations?**

Plotting a drawing, 3d printing a model or milling a piece of wood are processes in which the **software calculates the “optimal” or “average” operation to produce the physical manifestation of our ideas.** Nonetheless, unlike digital processes that occur inside a software, **designers don’t ‘make’ according to calculations of optimal data.** Moreover, the process of creation is the result of a continuous circulation between the interaction between body and its senses (primarily vision and touch) , tools (pen, knives, scissors) and matter (clay , paper, ink, wood).

As Dreyfuss (1992) asserts *“A machine can, at best, make a specific set of hypothesis and then find out if they have been confirmed or refuted by the data. The body can constantly modify its expectations in terms of a more flexible criterion: as embodied, we need not check for specific characteristics or a specific range of characteristics, but simply for whether , on the basis of our expectations, we are coping with the object”*(p.250).

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To Dreyfuss(1986), it is clear that computers are indispensable for some tasks due to some characteristics where they surpass humans capabilities such as precision or exhaustion. Moreover, he asserts that computers are specifically useful in CAD applications due to their capacity to compute and process large amounts of information, improving efficiency by optimizing drafting, analysis and processing of tedious optimization , analysis and representational tasks(p.xii).

Nonetheless, **what happens if in the process of designing and making a prototype the designer ‘sees something else’ and need to reformulate that design in real-time?** How does this ‘black-boxing’ -which rarely happens in analog design processes such as drawing or model making- affects aspects of creativity and cognition of the design process?

ToFlusser (1991), our society lives a crisis in terms of creativity(p.43). The design practice through technology is constrained by the imposition of an hylomorphic model by a constant imposition of predetermined ideas over matter by “a violent assault on a material prepared ‘ad-hoc’ to be informed with Stereotypes” (Flusser, 1991, p.43).

Today’s digital design technologies work by relying in an operation model that imposes a linearity of events where in the transition from idea to prototype, the designer is forced to pause the creation, focusing on the representation of ideas neglecting the interaction between action in perception present in analog processes(Fig 10).

Moreover as discussed previously, the three problems identified- The black-box problem, designing through the generic and the creative gap- shows that the relationship between designers and machines never moved towards a more reciprocal way of

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### 2.3.3 The creative gap

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## 2.4 From operation to interaction

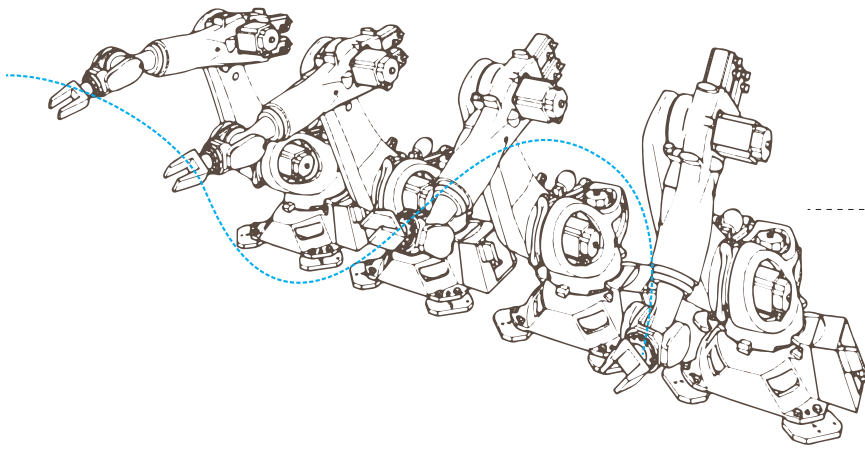
interaction but remained into the domain of the pure operation.

Hence, it is valid to ask, How to bridge Design and Making through the use of technology engaging the designer into more creative processes?. Moreover, How does the interaction between these antithetical worlds - the humans and machines- should happen in order to generate more insightful and creative design processes?. First, we must understand the relationship between designers(humans) and digital tools(objects).

As we move towards a more a technologized society, many questions still emerge in relation to 'humanlike-capacities of machine' and 'machine-like attributes of humans'. Furthermore, concepts like 'non-human agency' , 'human like machines' , or 'smart machines' appeared and populated the discourse related to HCI, especially in the fields affiliated to arts and creativity.

According to Idhe (2003, p91), the relationship between humans and technology could be explained through the concept of "intentionality" and what he calls "middle ground" or "area of interaction" or "performance". Idhe asserts that the only way to define or understand the relationship between humans and non humans is through **actional situations** that happen in an specific time and place. Furthermore, conversely to what Latour asserts, Idhe argues that this relationship is an asymmetrical one.

Moreover, this concept of performance talks about **real time interaction** in which not only humans but also objects -which Idhe and Latour refer as the "non humans"- are redefined as a new entity which Latour determine as a "Sociotechnical" Assemblage (1994, p64), derived from this interaction that transforms both human and non human into something else. In this case, In this case, Idhe(2003) argues that both human and objects enter into a dance of agencies "as the human with-intentions" (p.94) enters into the resistance and accommodation of mechanic agency provided by



the object. The actions and products derived from that interaction are possible neither by the human nor by the object, but by the relationship and actions enacted by their interactions.

In relation to this, it is possible to argue that in the design field, specifically in analog design processes, tools become almost invisible to us and act as mediated objects so the designer focuses in the specific action of 'making something'. Clark's (2004) interpretation about the relationship between humans and technologies according to degrees of transparency (p. 37), might be a useful perspective to understand why the problem of the generic, the creative gap, and black-box are relevant for today's design practice through technology. To Clark(2004) the difference between 'opaque' and 'transparent' technologies, relies on the degrees of transparency according on how well technologies fit our individual characteristics as humans(p.37).

The more intricate and hard to use the technology is, the more opaque it is in relation to how it deviates the user from the purpose

Fig 10

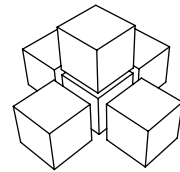
### Linear operation

Designer



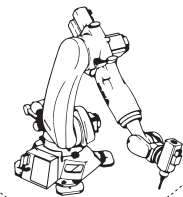
translation1

Model



translation2

Machine

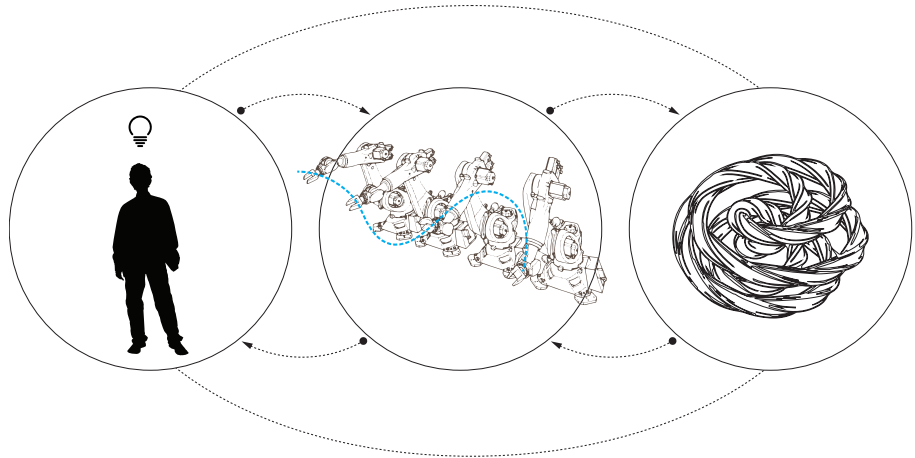


translation3

Prototype



Fig 11  
Interaction Model



of its use. Suffice it to say that the current model imperative in today's digital design practice is based in pure tool operation neglecting the idea of real time interaction and leaving important parts of cognitive processes of design aside. I argue that the many intricacies of digital tools -the black-box-, lead the designer to engage and focus in the elaboration of plans for representation -the creative gap-, that in many cases lead to rely in the software to solve a specific design problem -the generic- relegating the action of design to a initial effort which is later rationalized by a fixed structure.

Finally, in order to propose a model of interaction that transcends the 'hylomorphic' model imperative in today's architectural design practice to a more reciprocal form of computational making, we must explore real-time interaction between mind, body, and tools by using body gestures and imbuing fabrication machines with behavior in order to establish a dialog, which embraces ambiguity and the unexpected to engage the designer into improvisational, insightful and cognitive design processes (Fig 11.).

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# Human - Tool Interaction

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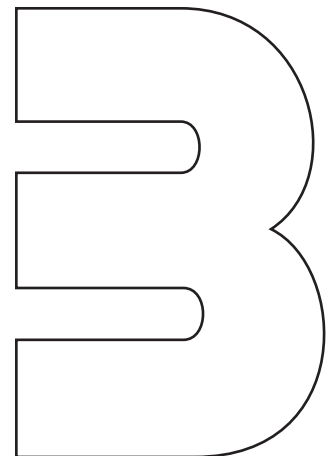


Fig 12

Glass Lab MIT



### 3.1 Tools for representation vs. tools for creativity: an enactive approach.

According to Schön (1987), design is a form of artistry and making, where learning about a specific topic or design emerges through actions (conscious and unconscious) and exploration (p. 29). The designer learns how to design by knowing and “reflecting in action,” reinterpreting and re-elaborating actions in the particular moment where the act of design takes place, producing new meanings and coherence (Fig 12 -13). In addition to this, Ackerman (2004) asserts that humans express ideas by making them tangible and shareable “which, in turn, helps shape and sharpen these ideas... We can only negotiate meaning through tangible forms: our own expressions or existing cultural mediations (language, tools, toys)” (p. 6). Furthermore, this suggests that every creative process is accompanied with a material representation that is a by-product of a constant interaction with our surrounding objects. Moreover, as Tilley asserts “material things, unlike words, are not just communicating meaning but actively doing something in the world as mediators of activity” (as cited in Malafouris, 2013, p. 11). By interacting with our surrounding objects, we learn and produce meaning and therefore reason. As Robinson (2013) argues,





Fig 13

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reason, that is the power of the mind to think, understand, and form judgments by a process of logic, is actually a proprioceptive circulation of the relationship between mind body and things around us (p.60).

Digital tools (e.g. the computer, 3d printer, laser cutter, CNC milling machine) are commonly used to perform a task (a set of prescribed rules), which can be coded on an algorithm or defined inside a parametric model as a set of topological relations. In contrast, if design is considered as an activity, moreover, a cognitive one, it can be referred as “the way people actually realize their tasks on a cognitive level”(Visser, 2006, p. 28) by using knowledge, information and tools. Taking this into consideration, the problems identified in the previous chapter can be related to the use of digital tools (CAD-CAM) as task performing machines instead of activity performing machines. In other words, we program our machines to perform several tasks, however we don't interact with machines to perform an activity in the way Visser claims. In addition, the little interaction between creator and executor (that is, designer and

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**3.2 Interacting with the surrounding environment: tools and hands as cognitive artifacts for creativity.**

machine) is constrained to an insufficient interface (clicking and typing) to grasp the main qualities of both worlds to engage in more creative processes.

In relation to the concept of 'tool,' a relevant question that emerges is whether the computer a design tool or a production tool. If Design and making are considered as creative and cognitive processes that imply the use of artifacts, it is crucial to take into account some important considerations related to the use of digital tools in design, and how the dialog between the creator (the human) and the executor (the machine) exists.

As stated previously, in digital design processes, while the overall tendency is to follow the current model of interaction with computers through the use of common input devices such as the mouse or keyboard, it is valid to argue that digital tools can incorporate cognitive aspects present in analog design processes to engage creativity in early design stages beyond its use as efficient productive tools. As an example, in analog design processes, the designer uses different tools to create a design such as pencils, rulers, paper, scissors, and knives. These tools are part of a repertoire of cognitive, symbolic, and semiotic artifacts by which the designer makes things to solve a specific design problem. Moreover, in this creative process, designers interact with these tools by assimilating and incorporating them as an extension of their bodies (Malafouris, 2013, p. 7) in a similar way as Bateson describes:

*“Consider a blind man with a stick, Where does the blind man’s self begin? At the tip of the stick? At the handle of the stick? Or at some point halfway up the stick?”* (as cited in Malafouris 2013,p. 4)

According to this example, tactile sensation is projected from the hand to the tool, and through time and practice the tool becomes incorporated and transparent (Malafouris, 2013, p. 7). Leder asserts, by his concept of “phenomenological osmosis,” the body

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*“brings within itself novel abilities, its own temporal history, and tools that remain spatially discrete”* (as cited in Malafouris, 2013, p. 34). The concept of **tool embodiment** is crucial to analyze and discuss about the use of machines in design - and why this topics should demand the attention of designers - especially because of assumptions about the use of technology in design as a liberating agent of creativity for them.

In addition, the use of technology in design demands our attention because little or nothing can be found about the shortcomings of the current model of interaction with machines for design and how it may lead to an incomplete or biased interaction in relation to cognitive or creative processes by only focusing in the representation both digital and physical. The way we interact with parametric software or fabrication machines is constrained to a one-way communication based on external representations of things. Furthermore, through clicking and typing, designers give shapes to different geometries and translate their intentions of the design in a visual way through rendered images, technical drawings or interactive visualizations among other types of representations. Moreover, if the aim of the process is to generate a physical output, digital fabrication techniques enable designers to generate prototypes of the designs. The one-way visual communication established between human and machine at the different stages of the process (from mind to software, from software to code and from code to material) shows why the process seems to be insufficient or at least incomplete in terms of material and tool feedback.

Moreover, according to Radman (2013) tools are ‘negligible’ artifacts that remain invisible to us until we attend to, and treat them by handing them (p. 372). Radman asserts that this objects transform for us the space into an environment shaped by motor significations, which inspire most of our motor behaviors (p. 377). In addition, Gendlin refers to objects as clusters of behavior possibilities by saying that Many possible behaviors come with any object “The objects exist not just in locations but also in the

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### 3.3 Design as an embodied activity

space of behavior possibilities. That is behavior space in which we act and perceive”(as cited in Raman, 2013, p. 155), thus, space becomes hand centered. Radman (2013) writes, “*what we do with our hands shapes the way things are seen, remembered, imagined, or generally kept in mind*”(p. 378). According to this, one can say that the limited physical interaction between designer and computer that the current model offers seems to underestimate the possibilities of the senses and actions of the body in the creative process. This is true if we take into account the idea of the body as a crucial component in the way we think (Malafouris p.60).

In this construal of the embodied mind, an interesting approach is the one made by the Material Engagement Theory. Malafouris (2013) argues that action is a form of cognition and that human cognition is not situated in the head but in our entire body (p.14). Furthermore, an interesting concept introduced by Andy Clark (2008) is the “leaky mind” (Clark, 1998) presented in the Extended Mind Theory (EMT) by which he explains that the local mechanisms of the mind are not exclusively in the head “cognition leaks out into body and world”(p.xxvii). Likewise, Malafouris (2013) explains from an enactive perspective how humans think and learn through things by engaging our surrounding material environment (2013, p7) and how the mind extends from the head to the objects we touch and interact with. According to Robinson (2013), the EMT “*is the notion that in specific kinds of mind-body-world interaction there emerges an extended mind or extended cognitive system that doesn’t just use but incorporates the pencils, paper, computers, and other extra-cranial objects and environments we use to help overcome or work around our brain’s klugey design flaws*”(p.1). The hand, gestures and the use of tools as mechanisms by which we learn and think is a crucial aspect of why the revision of the process of design through technology is relevant. According to Lakoff (1987), “*the very structures on which reason is based emerge from our bodily sensorimotor experiences*”(p.371).

In addition, Ingold (2008) asserts that in every creative endeavor

*“the role of the artist is not to reproduce a preconceived idea, novel or not, but to join and follow the forces and flows of material that bring the form of the work into being”*(p.17). Furthermore, is this interaction between mind and tool the one that Robinson (2013) calls ‘Circulation,’ in which tools become externalized mind, and cognition as internalized tools (p.35). This circulation is crucial to comprehend the role of digital tools (software and hardware) in the creative part of design and to discover the affinities and dissensions that can be established by using tools as ‘objects to sense’ and ‘objects to think’ with. The mind-tool interface, as Robinson (2013) argues, is not a static one, but one that implies a bi-directionality where humans – in this case designers – internalize tools as mind and externalize mind as tools as a “proprioceptive circulation”(p.60). **Thus, it can be argued that sense and action as gestures play a crucial role in this negotiation.**

In January of 2015, Victor Leung<sup>1</sup> and I taught the Workshop ‘Constructing Numerical Control’. The workshop took place at the school of architecture of Hong Kong University as part of the Winter Workshop Series 2015 which had a duration of 5 days. During the workshop, students were invited to learn about technical concepts behind the building and operation of CNC machines for architectural design and fabrication (Fig. 14). Through lectures and hands on sessions, students were encouraged to design 4 drawing machines and generate through coding or visual programming, the tools to operate/interact with them.

Using Kits provided by MAKEBLOCK<sup>2</sup>, students built 3 drawing machines and one milling machine. Specifically, one of these prototypes, was of particular interest for this thesis due to the implementation of principles that required, on the one hand programming automated routines to write Chinese calligraphy and on the other implementing interfaces to control in a more fluid way the machine to achieve the same goal.

Moreover, during the lectures, the students- which had no experience in programming- were taught to generate through the

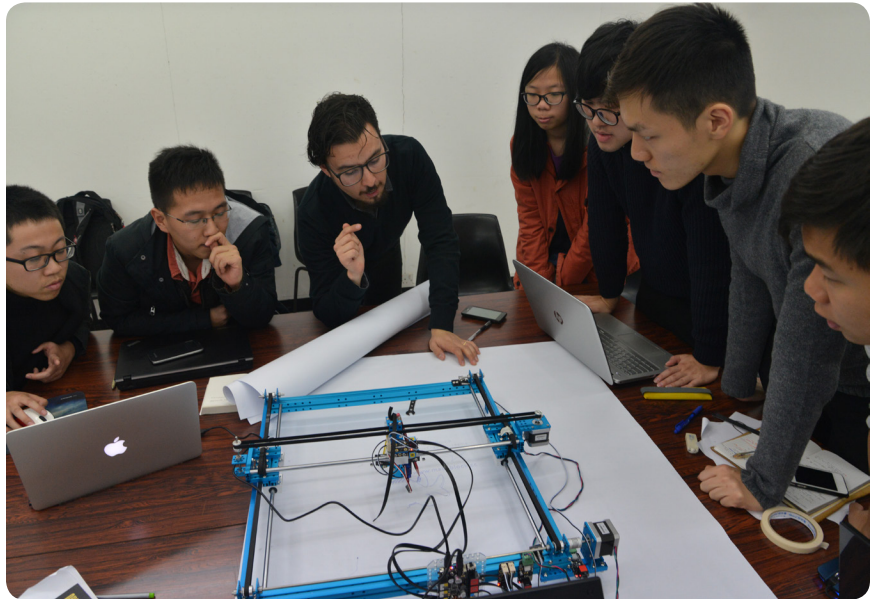
### 3.4 Robotic calligraphy: operating vs. interacting

<sup>1</sup> Victor Leung is a Graduate Student at the SMarchS in design and Computation at the Massachusetts Institute of Technology

<sup>2</sup> [http:// www.makeblock.cc](http://www.makeblock.cc)

Fig.14

Constructing Numerical Control Workshop,  
Diego Pinochet and  
Victor Leung 2015



visual programming language GRASSHOPPER 3D<sup>3</sup> automated routines (G code) to control a drawing machine with an attached paintbrush. The goal of this particular project was to program a machine to write Chinese characters trying to emulate a skillful practice that usually requires a special coordination between mind, hand, eye, and tool (Fig. 15). The purpose behind the goal was to test a procedure that sought to capture aspects of the particular act of tracing through the use of technology. Moreover, because Calligraphy, is based in the freehand imitation of technical skill models as a way to produce original work(Nakamura, p.82), it constituted an interesting example to explore ways of understanding the affinities and dissensions of humans and machines in relation to creative processes

The first part of this exercise had the purpose to test if specific actions and movements could be translated as a set of rules that a machine could follow to write the characters for the word 'ARCHITECTURE' (Fig. 16). Moreover, because Chinese

<sup>3</sup> <http://www.grashopper3d.com>

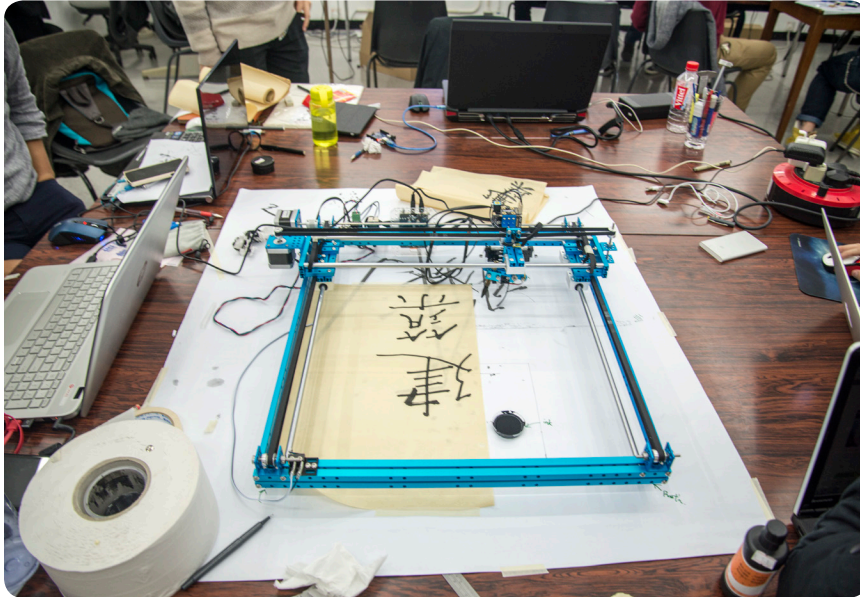


Fig 15  
2 Axis CNC machine  
with paintbrush. early  
tests

calligraphy is a type of writing closely related to expression of life and motion through traces, it required the consideration of many material factors such as: type of brush, color and density of the ink, absorption speed and texture of the paper (usually rice paper) but most of all physical factors related to the body of the calligrapher and the tool used such as direction, speed, pressure and inclination of the brush to perform the traces. Furthermore, beyond the material factors involved, there were additional parameters, where vision and action were key aspects taken into account such as the 'dipping factor' in relation to the quantity and density of the ink and the absorption/spreading factor of the paper. Considering these parameters, resulted in a long definition of procedures related mostly with motion expressed as GCODE(Fig.17). The type of commands generated were divided in two types (Fig 18): tracing movements (free/exploratory) and auxiliary movements (fixed/combinatorial).

Fig 16a  
step 1 - manual tracing.

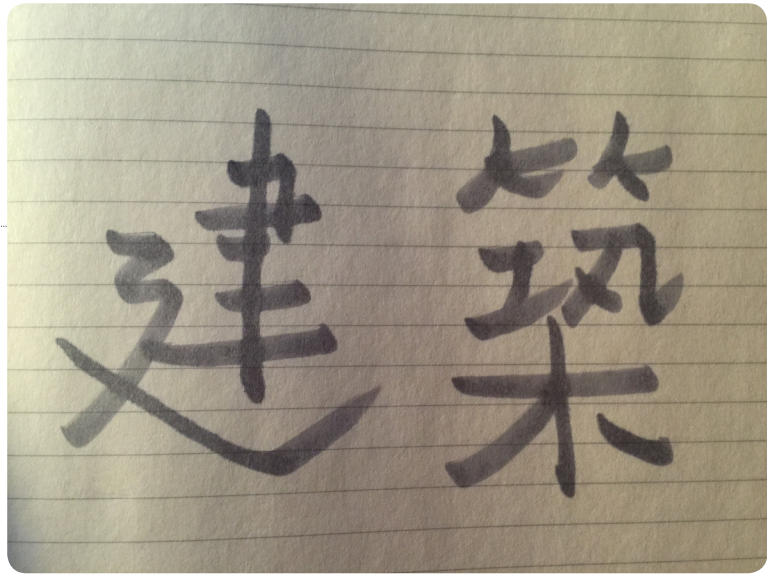


Fig 16b  
step 2 - Using Computer  
vision, detect blobs.

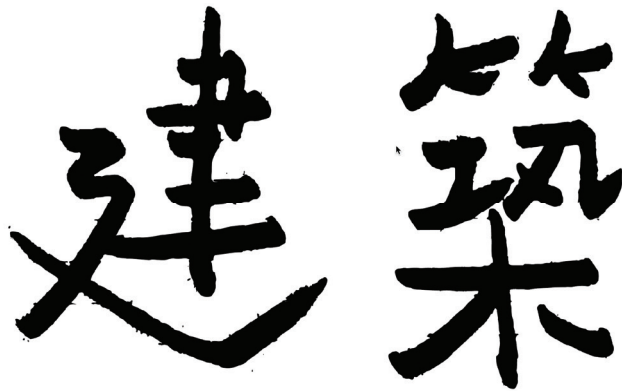
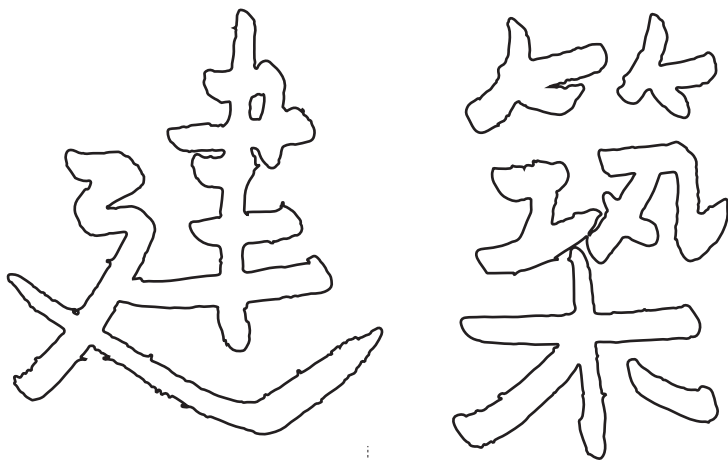
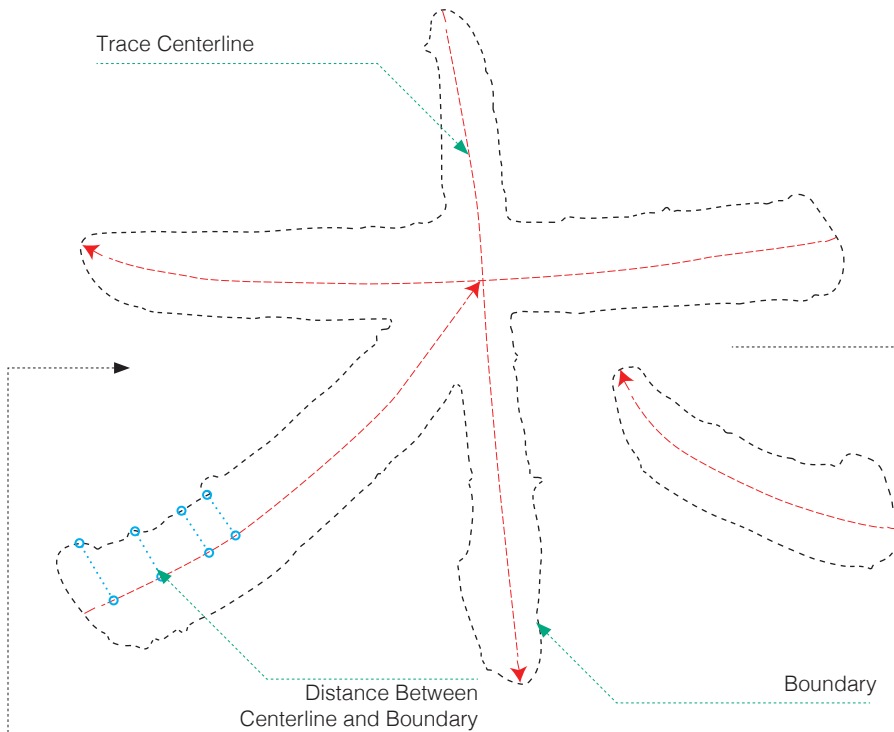


Fig 16c  
step 3 - Extract boundaries.







Contemporary Calligraphers, follow a very structured model that seeks the development of traces using multiple brush movements<sup>4</sup> known as 'tahetsu-ho'. Moreover, one common form of this model is the 'Three brush movement' which is composed by three specific moments: 'Kihitsu' (starting a stroke), 'Sohitsu' (pulling the stroke) and 'Shuhitsu' (ending the stroke) (Nakamura, 2008, p.85). Nonetheless, behind this rigid structure of movements, lies hidden the truly essence of calligraphy: If 'Kihitsu' and 'Shuhitsu' can be related to a preparation action that initiate/finish another action that require a full coordination of eyes, body and tool, is in the moment of 'Sohitsu' where the calligrapher impresses his/her inner self into the canvas and where the original work emerges. Taking this into consideration, the project faced a huge difficulty in terms of translating this movements to a set of computational rules.

The tracing commands were specific tracing motions related to the specific parameters of the shape of the characters. Using computer vision algorithms it was possible to detect manual traces on paper as blobs, extract their boundary and use this information inside grasshopper to generate the G code. Moreover, to encode

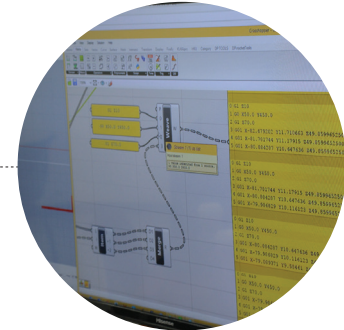


Fig 17a  
Grasshopper definition



Fig 17b  
G Code

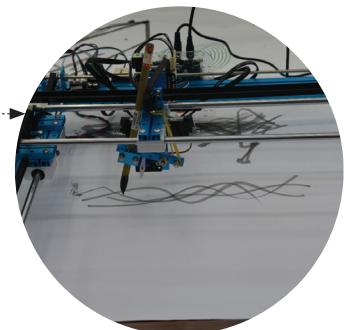


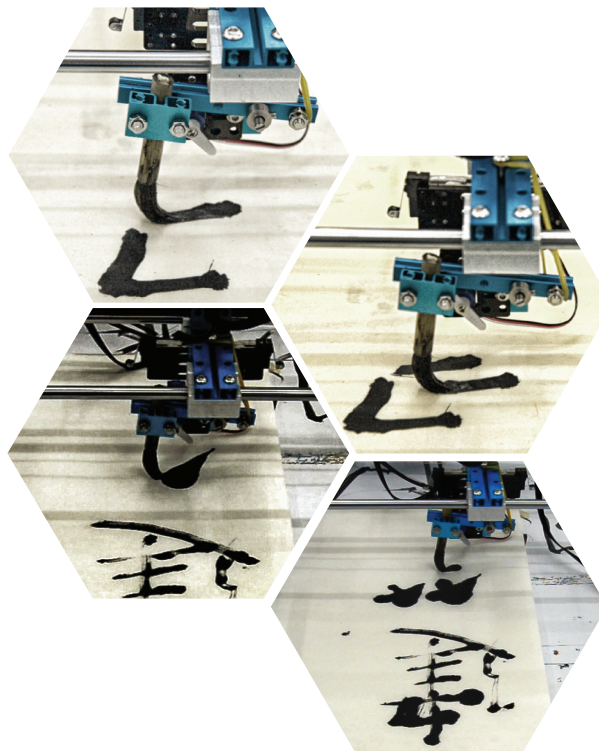
Fig 17c  
Machine motion

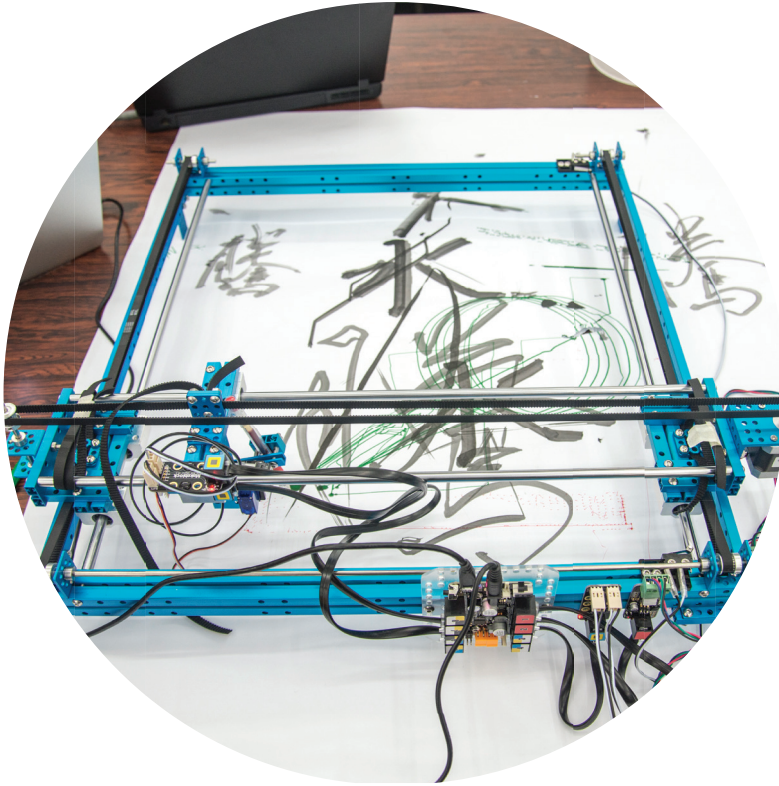
4- Developed during the Tang Dynasty in China by Huang Tingjian (1045 - 1105). (Nakamura p.85)

Fig 18a  
Example of auxiliary  
movements: Dipping  
and shaping the brush.



Fig 18b  
Tracing Movements.



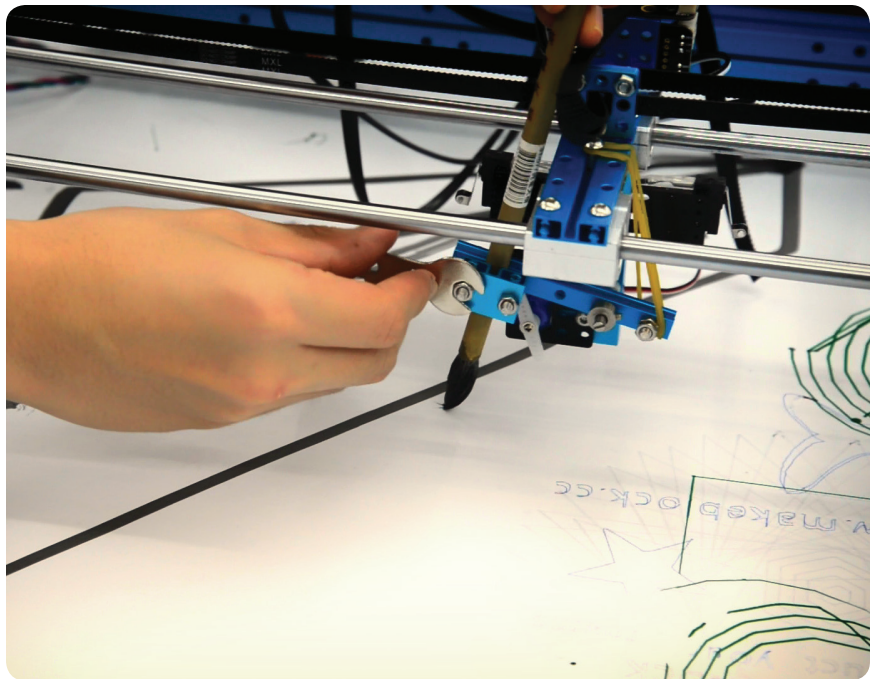


these motions, it was necessary to take into consideration the pressure factor, which in this case had to be managed by an indirect parameter evaluating the distance from central curve of the shape (mean curve) and its boundary. Moreover, this distance parameter was translated afterwards into a 'pressure parameter controlling the 'Z' (height) value of the brush to perform thicker or thinner traces. Finally, a last parameter considered for the generation of the tracing commands had to deal with the speed of the trace, which required the generation of the second type of commands: the auxiliary movements.

The generation of the auxiliary movements had to deal with the 'material' factors such as texture and absorption of the paper, and the density of the ink. Moreover, these commands were linked to one parameter, 'the dipping factor,' to ensure the quality of the traces. Moreover, the dipping factor was determined by the length of the trace and the its pressure, which specified the frequency of the dipping action into the ink container. A final auxiliary movement dealt with 'shaping' the tool, by performing a 'cross movement' to

Fig 19

Fig 20  
Adjusting the brush



shape the tip of the brush after dipping int in the ink.

After performing a set of 23 drawings(Fig 19) - with a wide range of results that varied from complete failure to nearly successful drawings in terms of legibility and quality of traces- it was possible to conclude some aspects about the use of customized digital tools to emulate or replicate skillful practices such as hand drawings or Chinese calligraphy writing.

One conclusion about this exercise, was that in order to grasp the many factors involved in the action of tracing, the visual and the gestural were essential aspects of the tracing process which were very difficult -if not impossible- to 'automate'. As Nakamura (2008) claims, the calligrapher creates lines that are expressive gestures shaped as traces on paper knowing how the coordination between body , hand and brush result in different kinds of traces (p. 85). Moreover, because of the uncertainty amidst the different behaviors - material and human- which emerged during the act of tracing, it was clear that the linearity of the processes developed

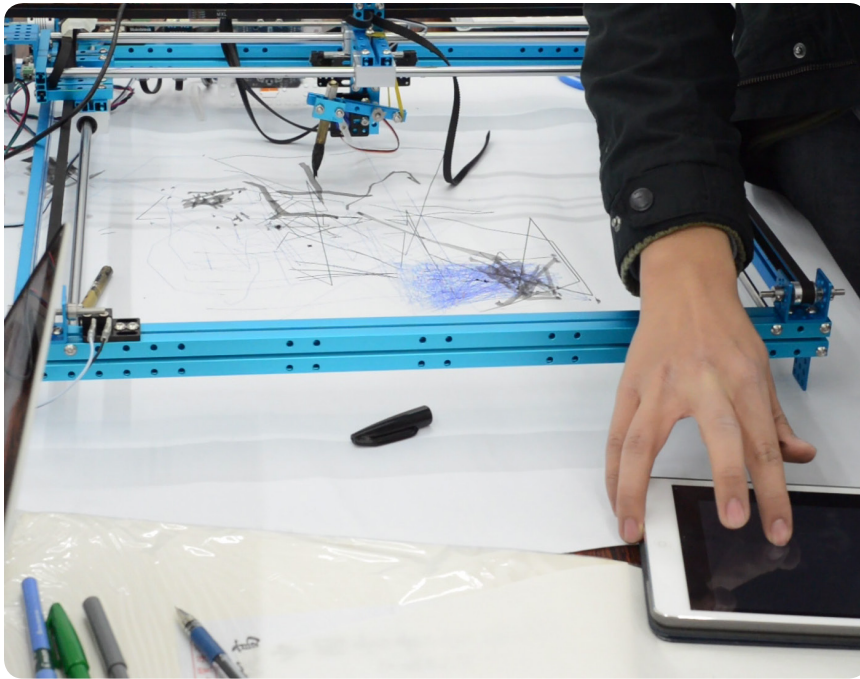


Fig 21

Interaction through  
tablet device

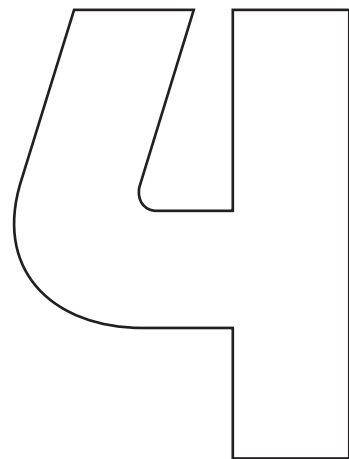
were based on machine operation, leaving aside the 'performative' part of doing calligraphy out of the process(Fig. 20).

Furthermore, the project in terms of achieving the main goal failed, proving to be insufficient in order to perform in a similar way as a skilled calligrapher mainly because I tried to frame into a rigid combinatorial structure modified by discrete parameters, the myriad possibilities that emerged from the 'human aspects' of this practice that are related mostly to ambiguity and unpredictability. Furthermore, not only to Chinese Calligraphers but to the Japanese, calligraphy is an act that reflects one's personality -known in Japanese as 'sho wa hito nari' or 'writing is like the person'(p.83)- which makes reference to a process of self expression that appears only in the very moment of the tracing performance, hence, impossible to frame as a set of mechanical procedures beforehand. The problem of translation from mind to , code to , machine to , drawing couldn't be addressed by the pre - structured set of rules.

Finally, because many of the efforts were focused on the creation of automated routines following this linearity from code to action, it was evident that the limited or null interaction with the machine in the very act of tracing, the three problems identified in the previous chapter (the blackbox, the creative gap and the generic), emerged relentlessly. On the one hand, the enterprise of emulating an embodied process in this way was very inefficient in terms of time and on the other, it needed human intervention in almost every step, except in the very act of the tracing which was in the end the most important one.

As a final exploration I implemented real-time control in the machine using a smartphone and tablet. The touch screen allowed us to have a more fluid interface incorporating real time control of the brush, achieving better results by integrating in a more dynamic the gestures(Fig 21). Because of time limitations of the workshop, this alternative was not implemented exploring its full capacities.

Nonetheless, after this exercise, it was clear that to solve computationally the challenging sensory and aesthetic problems of 'creating' through machines in a similar way as analog processes, we must embrace the concept of Interaction. Moreover, we must move towards more reciprocal processes integrating digital tools, not only by focusing in the creation of plans for action/representation, but on models for interaction embracing the perceptual and actional aspects of creative processes to reconcile 'design and making' as an embodied activity.



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**MAKING GESTURES**

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## 4.1 Project overview

In this chapter I present a novel approach to design through technology, building upon the theoretical discussion and the empirical approach of previous chapters. I introduce a novel system for interactive design and fabrication, by using body gestures and artificial intelligence allowing designers to use digital tools in a more improvisational way.

In the first part of this chapter, I introduce the components of this interaction model: the human as gestures, and the machine as a mediated tool. From the previous discussion, I conclude that, in order to augment our creativity and cognition engaging exploration, speculation, improvisation and knowledge production about designs, we must transcend the hylomorphic model imperative in today's design practice toward a more improvisational and reciprocal way of computational making by integrating humans and tools into a proprioceptive feedback loop.

Moreover, I propose that in order to solve the current problems of digital tools implementation in design - described in the second chapter- in terms of creativity and cognition, we must move from a model of operation, to a model of interaction, reconciling design and representation/making into a more performative process based on action and perception. **The idea allows me to answer some of the initial questions related to the unique characteristics of designers as creative individuals and how through the use of technology we could impress that uniqueness into our surrounding environment focusing on gestures.**



In the second section, I discuss the development of three projects as empirical approaches to a model of human machine interaction for design. I describe the development and implementation of three types of interaction using a 2 axis CNC drawing machine and a custom software interface. The three implementations are: Gestural interaction, Tangible interaction, and Collaborative interaction. In order to develop the three projects I have incorporated different sensors such as hand tracking devices, web cams and body tracking devices. The developments of these projects allowed me to integrate them to formulate the 'MAKING GESTURES' project exploring real time design and fabrication.

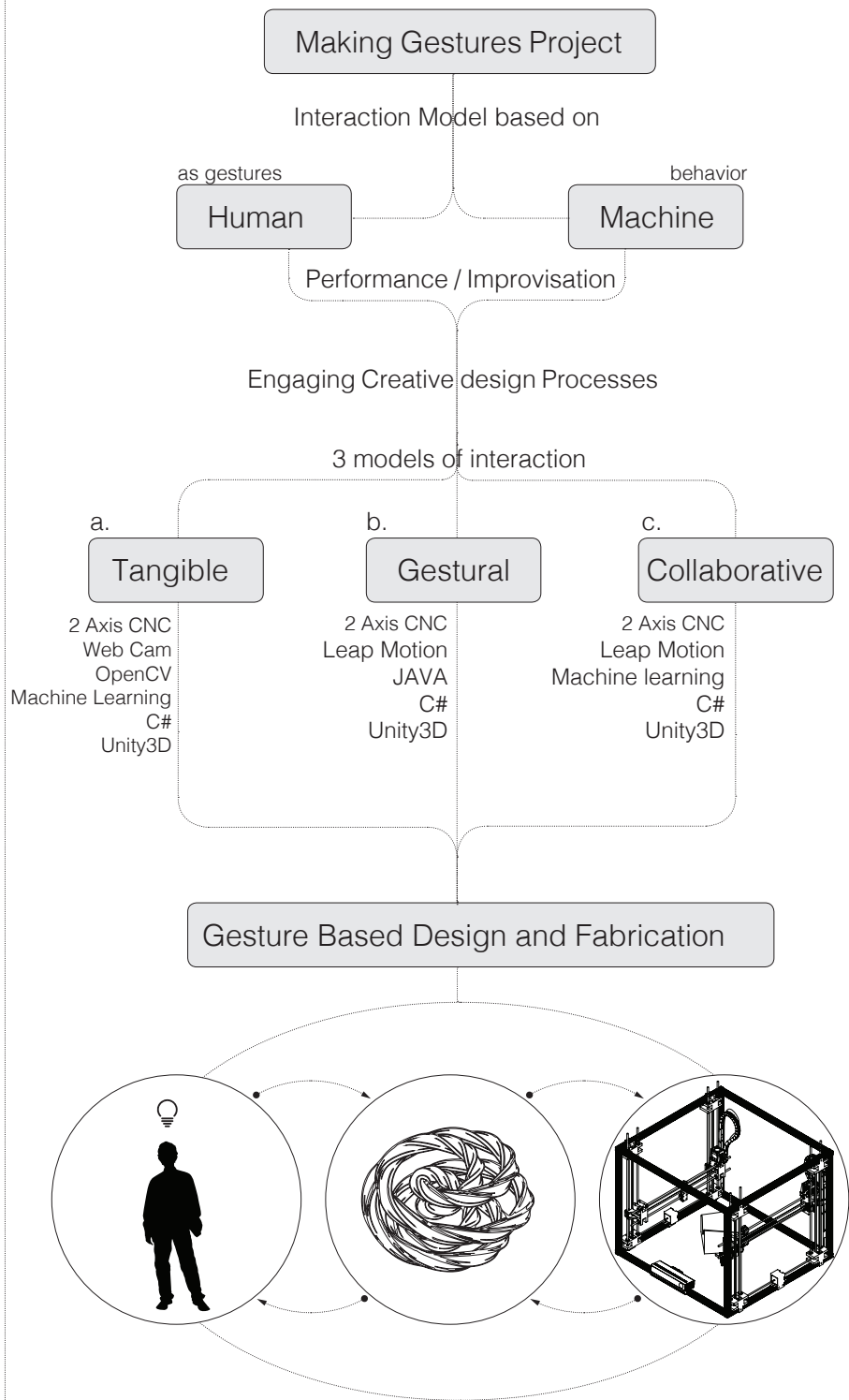
In the final section, I discuss the development of MAKING GESTURES, an interactive Gestured Based Design and Fabrication system. With this project, I explore real-time interaction between mind, body, and tools by using body gestures and imbuing fabrication machines with behavior, in order to establish a dialog which embraces ambiguity and the unexpected to engage the designer in insightful design processes. I start by describing and explaining the development and functions of a 5 axis CNC machine and the its hardware components from its design to its construction. Finally I discuss about the software development to interact with the machine by using gesture recognition and Machine learning as a way to establish a fluid interaction capturing and interpreting designer's improvisational gestures.

Fig 22  
Making Gestures  
implementation diagram

Why?

How?

(so)What?



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## **4.2 The middle ground: human + machines**

From the discussion in the previous chapters, it is clear the position of many scholars- from psychological and anthropological perspectives- related to the role of 'embodiment' in how humans learn producing meaning and reason by a constant interaction with the surrounding environment, has been very helpful to introduce and frame the main ideas of this thesis. Moreover, the concept of 'interaction' understood as 'performance' in a constant engagement between humans, tools and environment, has unveiled key factors to formulate how this interaction should happen. At this point, I argue that this interaction, which is based on action and perception unified, is the base to foster creativity and cognition in the design process. The development of design through technology should focus on interaction to grasp through improvisation the real-time contingencies of the world around us. Moreover, considering that design is not a process of making through following pre-structured rules but one of constant discovery -where rules and the actions derived from those rules emerge as new things are seen- the development of interactive systems is imperative in our practice.

This approach to design is related to what Ingold's approach to creativity (Ingold,2008) in which he refuses the combinatorial approaches to creativity such as Chomsky's linguistic vision of 'ruled- governed creativity', as the construction of comprehensible

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### 4.3 Why gestures?

expressions through infinite rearrangements of lexical items (p.47). To Ingold, creativity is more than a simple re-combinatorial generation of novelty. As he asserts, creativity is a *“movement, or flow, in which every element we might identify is but a moment.”*(p.47)

One conclusion from this discussion is that in order to reconcile design and making (Ideation and representation), we must develop new models of ‘real time interaction’ that are able to **‘capture the moment’** to solve the problems that constraint creativity in architectural design. I argue that by focusing in the **‘human performing’** in contrast to the **‘human representing’** we can move towards an understanding on how this interaction not only could, but should happen.

As discussed in the previous chapter, skillful practices such as calligraphy constitute useful examples to illustrate forms of creative artistic work using tools. Calligraphy is based upon a model of imitation and learning of precedents as ‘models of doing’. Through this process of copying, the artist acquire the different skills not to imitate anymore, but to express his/her uniqueness, impressing it to the material world(Fig 23). To calligraphers, the practice of ‘Rinsho’ is considered as the methodical imitation of procedures in order to achieve creative original work through three stages: 1) ‘Keirin’: learning by imitating the mechanics of brush technique.2) ‘Irin’: reproducing by interpreting intention. 3)‘Hairin’: reproducing based on memory allowing more freedom. Is the last stage of ‘Rinsho’, ‘Hairin’, the one that promotes the emergence of a personal style where original and creative work emerges by discarding the act of imitation/reproduction in favor of the expression of the self(Nakamura, 2008, p. 82). Is in the moment of ‘hairin’ where the artist, tools and materials enter into a choreography of agencies interacting and producing new types of ‘sho’<sup>5</sup>. **The emergence of the original happens not only because of the tension between historical precedents and the contingency of the moment, but also from the tension between human and object as gestures**

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5- Japanese word that describes creative artistic calligraphy

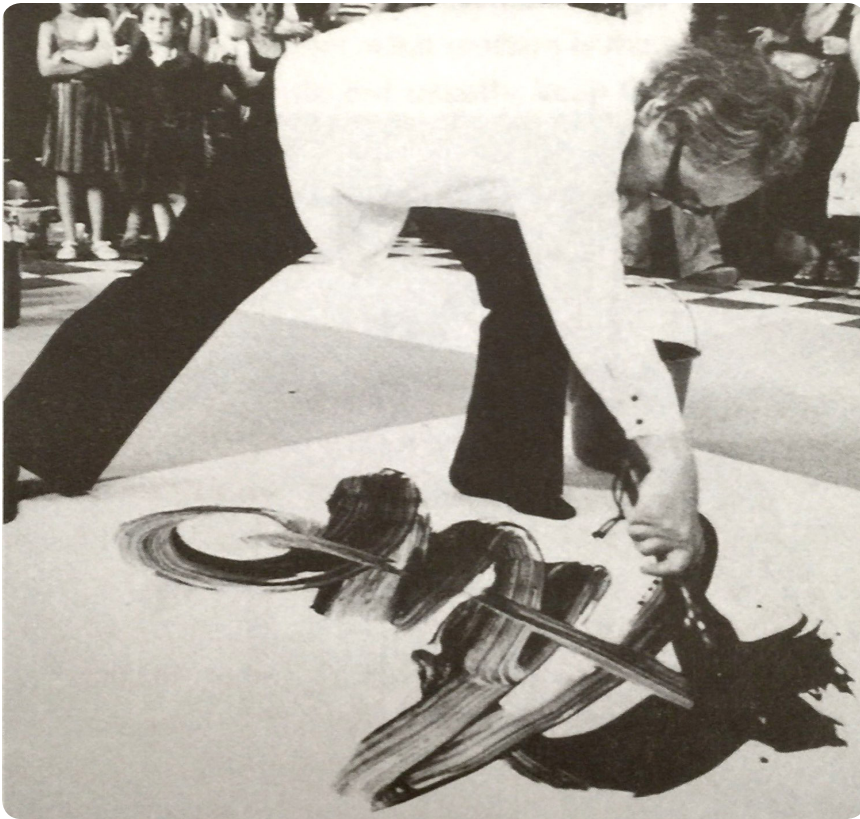


Fig. 23

Hidai Nankoku,  
Japanese calligrapher  
performing.

**that impress the uniqueness of the self onto the physical world.**

I asserted in the previous chapter that in current digital design practices, the current model of operation neglects the very aspect of performance leaving the human out of the process. The dichotomy between ideation and representation forces the engagement of the designer into a constant translation from idea to physical prototype, promoting the creation of plans for representation that **leads to a disembodied process where the performative act of improvisation totally disappears.**

As I have demonstrated through the discussion and the example of calligraphy as a creative art, that creativity emerges in the very moment of impression of the self onto the material world as an **improvised choreography** between humans and objects (materials and tools) **by using body gestures neither as action**

Fig 24  
Hansen, Heather "Emptied  
Gestures"



**nor perception, but as the unity of both.**

So the question to ask is, **Why gestures?** Because as I demonstrated in the past chapters, gestures have the capacity of embracing- beyond mental and intermediate representations- the moment of acting and perceiving (Fig 24 - 25). According to Flusser (1991), a gesture could be defined as “ *A movement of the body or of a tool attached with the body, for which there is no satisfactory causal explanation.*”(p.3), In addition , he suggests that a gesture is one “because it represents something, because it is concerned with a meaning” (p.4). This definition of gestures talks about how they are defined in relation to motion not only as an intention -which refers to a backwards understanding process that require to decode the movement in terms of its results and the causal explanation for it - but with a meaning - which is related to a forward understanding of the unfolding processes, as Ingold(2008) calls, ‘always in the making’(p.3).



Fig. 25

Stelarc. "The third hand" 1980

In the cognitive science field, gestures emerge as the manifestation of a continued motor regulation in the action, perception and anticipation cycle. To Maldonato (2014), body movements -gestures- are the result of an interplay between anticipatory(feed-forward) and compensatory(feed-back) mechanisms by which humans response to determined situations(p.59) not only by reaction but also by anticipation. The body uses feed-forward to prepare for action and feed-back to compensate that movement according to the sensory information coming from our multiple receptors(p.60). Moreover, the efficacy of this mechanisms as an active motor schema improves with experience(p. 60) through the use of what Maldonato calls 'Embodied action' which is a '*set of sensorial and motor schemas and habits, acting as a system able to recall corporeal perceptions*'(p.60). One can argue that gestures and the uniqueness of them as manifestation of the self, are the result of a constant relationship between Action, Perception and

Memory (which emerges from experience and learning).

The uniqueness of every gesture, can be explained by Schmidt's (1975) schema theory based in two concepts: The Generalized Motor Program (GMP) and the Motor Schema(Fig 26). While the GMP provides a motor pattern deposited in memory that posses different characteristics<sup>6</sup> that are invariant in the desired gesture, the motor schema adjusts specific selected parameters of that motor response to adapt to the situational demands. Maldonato(2014) Asserts that because of the relationship of these internal mechanisms, **the repetition of a movement - a gesture-will never be identical** (p. 61).

In a similar way, Suchman(2007), coined the term 'situated action', in which she refutes the dualism between plans and actions by her view that 'every course of action depends in essential ways to its own material and social circumstances to achieve intelligent action'(p.70). Moreover, I argue that gestures are the mechanism sby which humans can communicate with machines in order to establish a fluid interaction in order to capture the moments where creativity and original work emerges. **Finally, as i had demonstrated through the discussion, creativity and originality do not rely on the elaboration of pre-conceived ideas or plans, but on the relationship of perception and action as promoters of creativity and knowledge elicited, in which the concept of real time interaction through body gestures is the key to use digital tools in more creative ways.**

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6- Such as a) sequence of muscular contractions implied in a gesture, b) the temporal structure of the gesture and c) the relative force of each muscle applied in the gesture, (Maldonato 2014. p61)



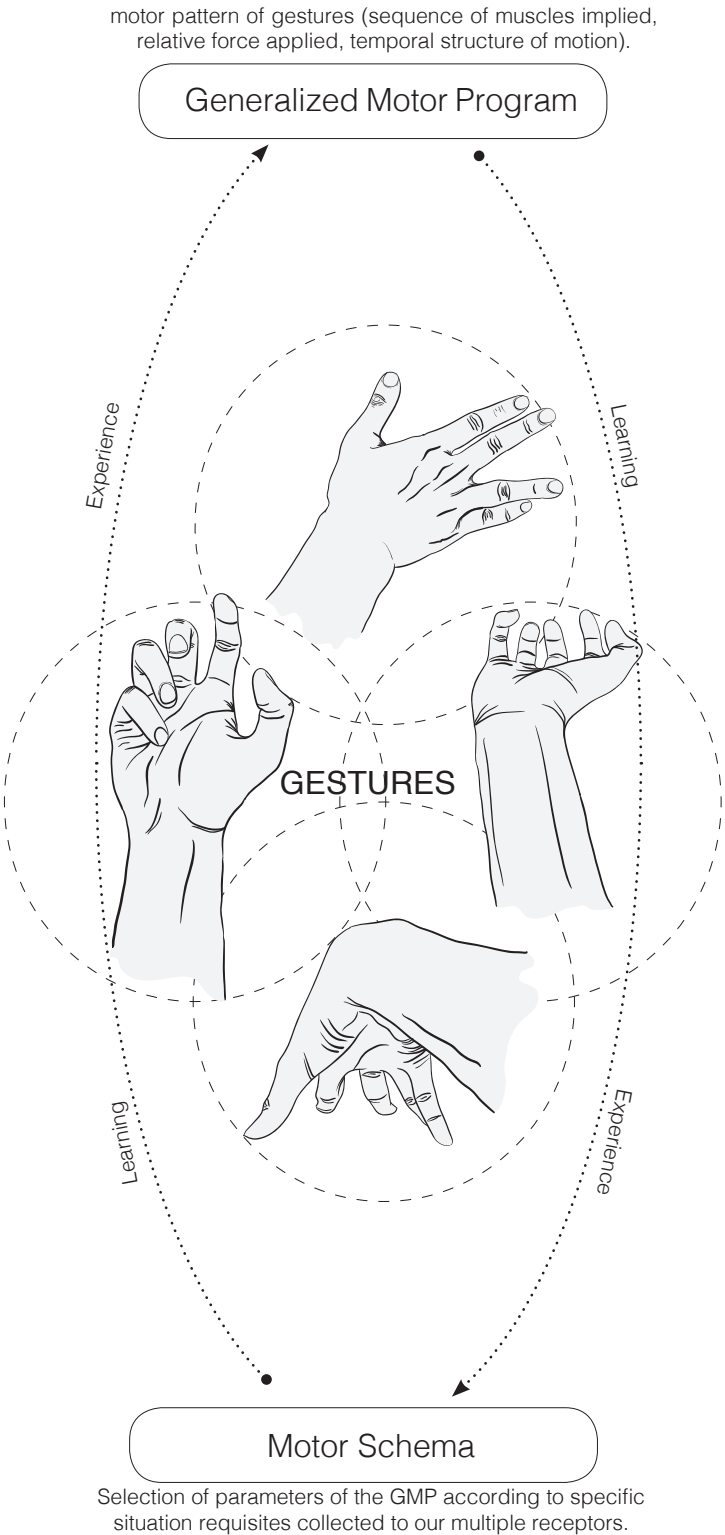


Fig. 26

How gestures work according to Schmidt's schema theory.

---

## 4.4 Why gestural machines?

As discussed in the previous chapters, in order to use digital tools - hardware and software- in more creative ways, **I argue that the development of interactive systems that capture the real time contingency between designers , tools and world is a must.** In order to generate this feedback loop between the constituent components of this relationship - humans and machines- we need to, on one hand, create tools that can capture that contingency (as gestures) and on the other, perform according to that contingency.

Is at this point where I argue that, by the development of gestural machines we can to solve the three problems identified in the previous chapters - the black box, the creative gap and the generic. Moreover, in order to foster and promote the improvisational aspects of design as exploration, we need not only machines that emulate the movement of the designer but machines that by the use of sensors and actuators can enhance our experience by establishing a constant circulation of action and perception from both sides. Nonetheless by stating this, **it's not my intention to seek the development of 'Intelligent design machines' nor focus in solving the peculiarities and dead ends that early cad proponents found after a few years of implementing similar systems.** My proposal here, is that we can take advantage of current developments on robotics, artificial intelligence , CAD and CAM in order to grasp in a computational way, the very aspects that make design a creative and original enterprise (Fig 27).

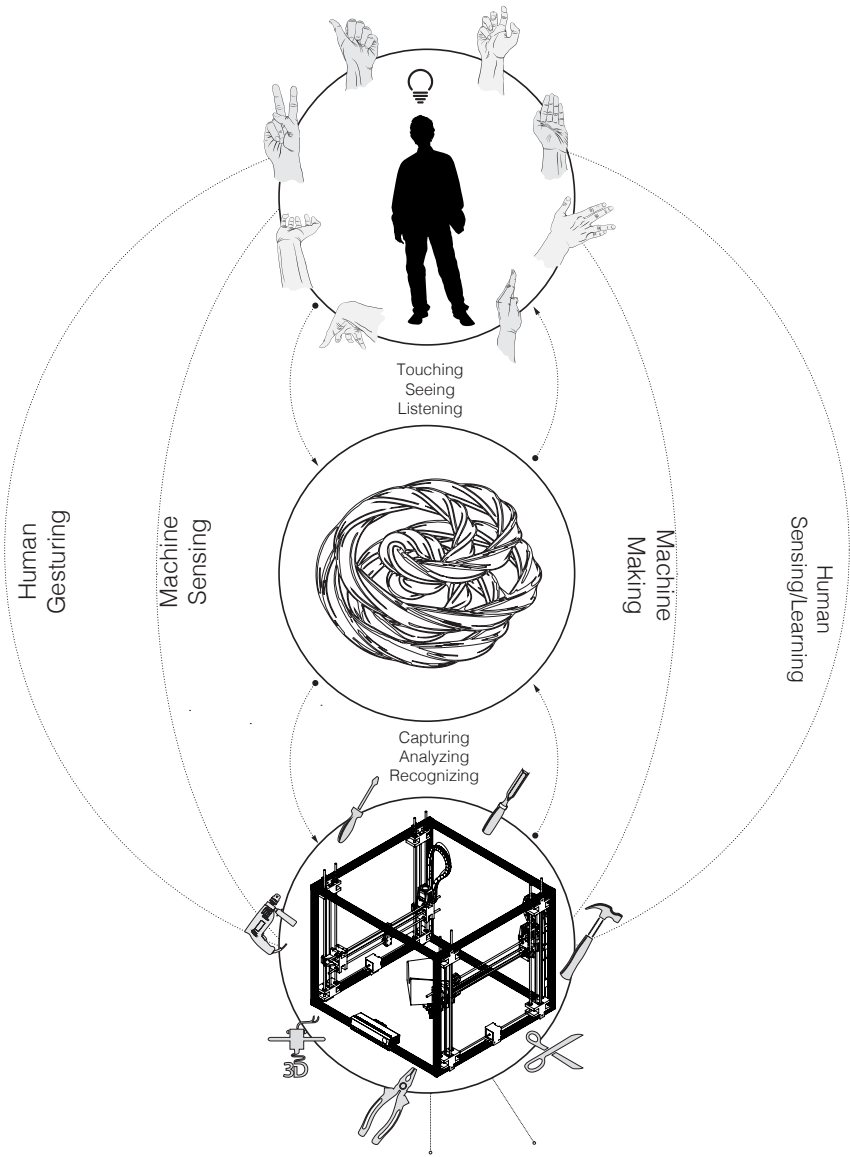


Fig. 27  
Machine interaction proposal diagram.

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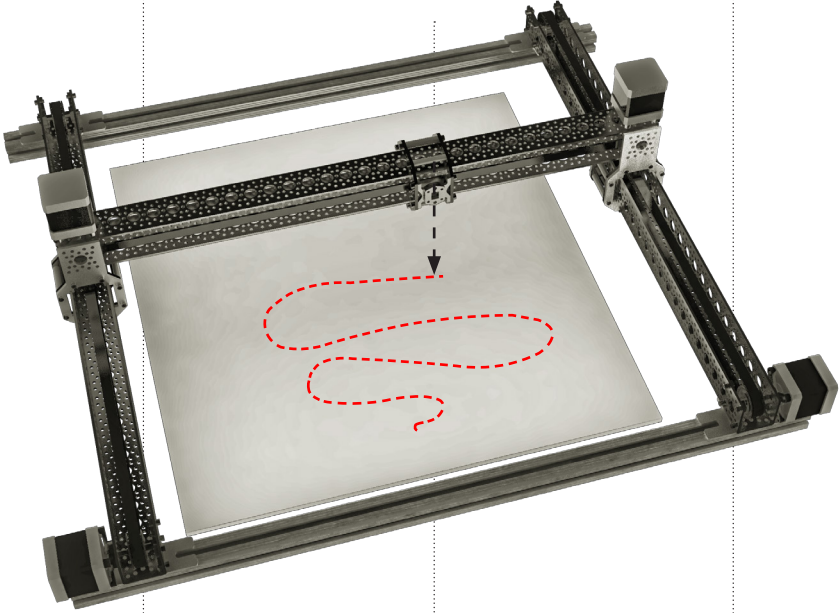
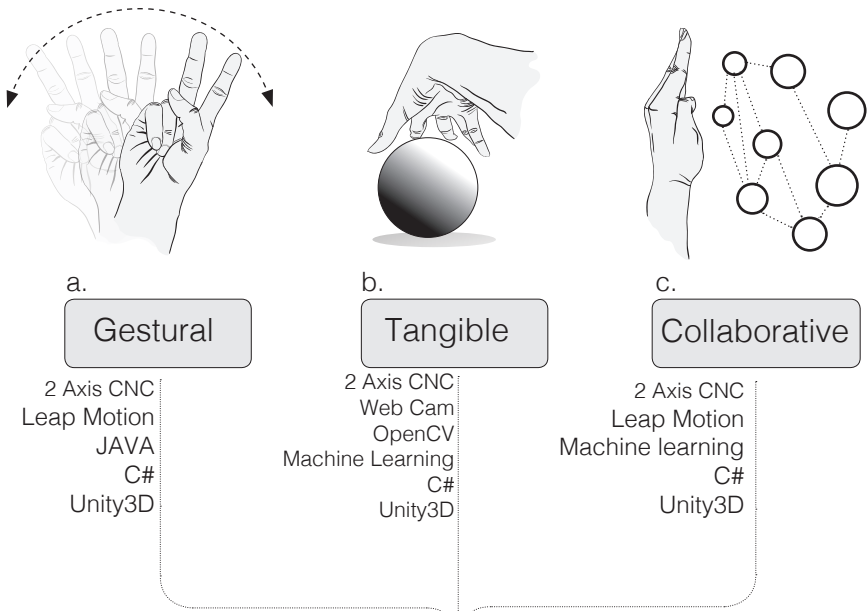
## 4.5 Interacting with the machine

This thesis proposes an alternative way of designing with machines embracing aspects of embodied interaction, behavior and communication between designers and machines. To do so, I propose the use gestures, tangible interfaces and Artificial intelligence to engage a more reciprocal way of making by the establishment of a conversation instead a mere dialog from creator to executor of a predefined plan. In other words, this thesis proposes a platform for interaction between humans and machines focusing in the exploratory aspects of design embracing aspects of improvisation, ambiguity, impression and discovery in the development of an idea.

In order to implement the interaction between humans and machines through gestures and machine behavior, I implemented three types of projects testing Gestural, Tangible and Collaborative interaction using a 2 Axis Drawing Machine connected to different motion tracking sensors and computer algorithms in charge of search, object and gesture recognition(Fig 28).

The basic Machine setup, consisted in a 2 axis CNC machine controlled by GRBL, an Open Source firmware for arduino capable of controlling using GCODE up to 3 stepper motors using one Arduino UNO board. In order to establish the communication with the machine and the different software implementations (programmed using different languages such as Python or C#) described in the next part, I used User Datagram Protocol (UDP).

3 types of interaction



Visual Feedback

Recognize 2 types of Gestures  
- Freeform  
- Fixed

Haptic Feedback

Manipulate Physical Object and translate motion to machine

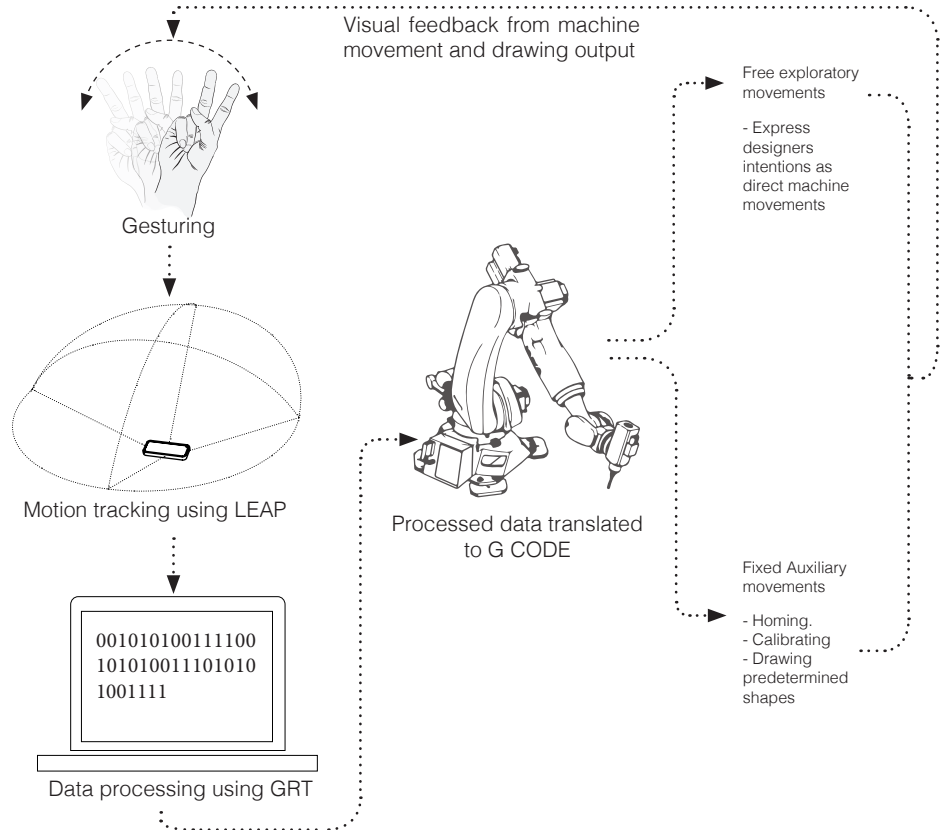
Machine Feedback

-Unexpected Behavior

Fig 28

Implementation of interaction types.

Fig 29  
Gestural Interaction diagram



### 4.5.1 Gestural interaction

Gestural Interaction (Fig 29), was implemented to test the use of Motion tracking sensors in order to interact with a CNC drawing machine, testing the use of gestures associated to specific operations. The goal was to recognize two types of movements, on one hand the free motion of the gestures in space as exploratory/ improvisational gestures, and in the other hand the auxiliary movements -as fixed operations to help the process of drawing.

To track gestures motion and get the data to perform gesture recognition I used the LEAP motion sensor<sup>7</sup>. This sensor, through the use of 2 infrared cameras is capable to track hands in space with high accuracy the position of hands and making a 3d skeleton model. The data from the 3d skeleton model was used to perform gesture recognition using Gesture Recognition Tool (GRT)<sup>8</sup> a machine learning C++ library created by Nick Gillian to perform real time prediction from sensor data using one specific algorithm implemented by Gillian. By using the Adaptive Naive Bayes Classifier<sup>9</sup> (ANBC), I was able to perform the recognition of

7- <https://www.leapmotion.com>

8- <http://www.nickgillian.com/software/grt>



Fig 30  
Gesturing

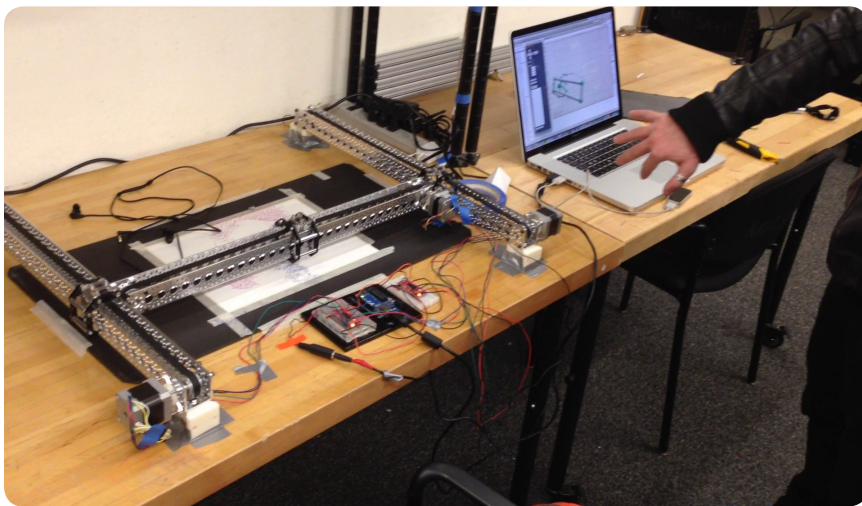


Fig 31  
Interacting with the machine

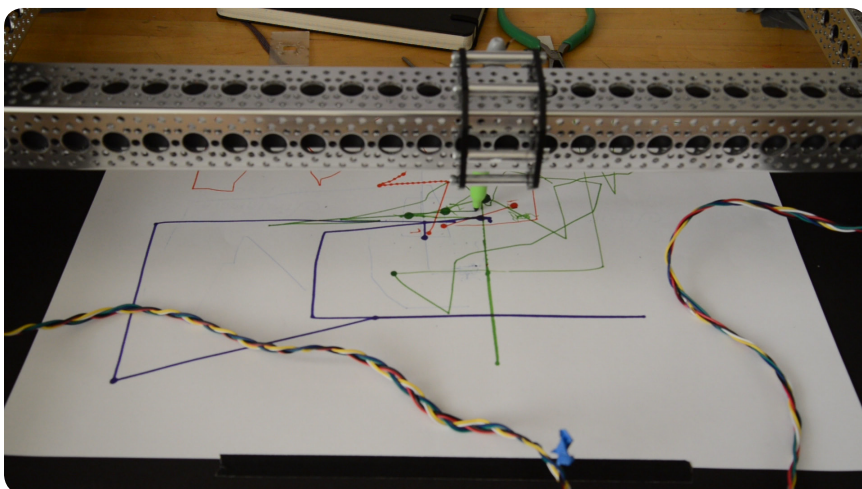
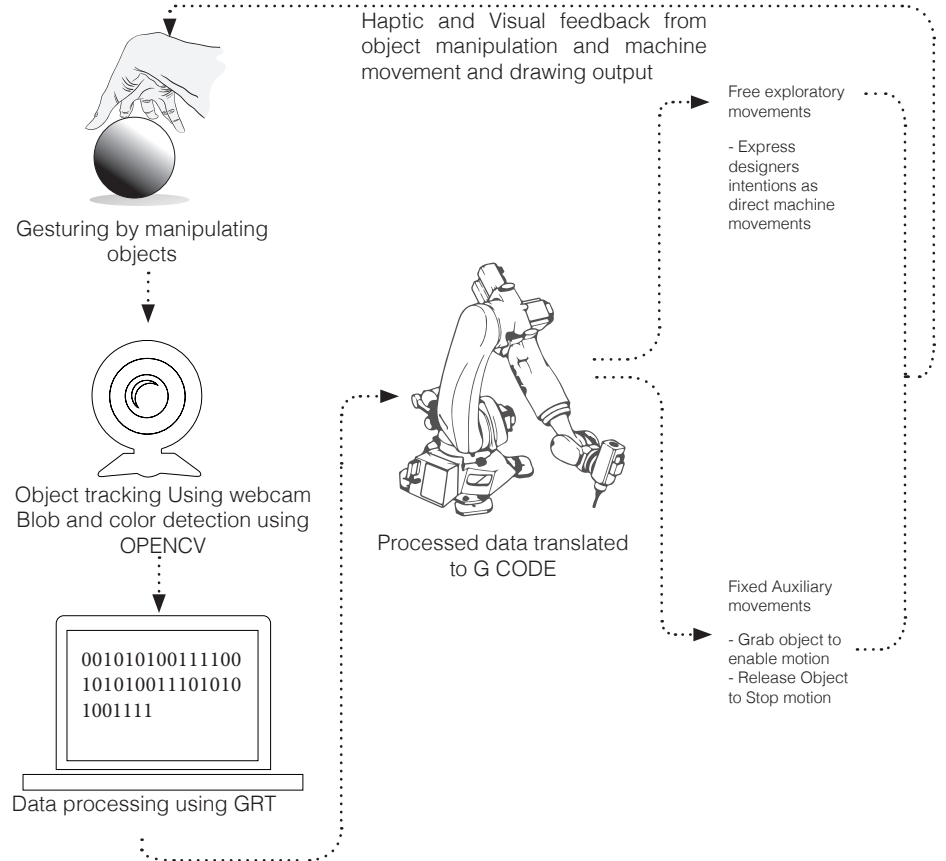


Fig 32  
Drawing output

Fig 33  
Tangible interaction diagram



custom gestures using the LEAP motion sensor. Initially developed to recognize musical gestures, the ANBC proved to be very useful to recognize other type of gestures from tracking sensors due to its capacity to perform prediction from N-Dimensional signals, its capacity to weight specific dimensions of that signal (if one parameter is more important than other), and most of all, its capacity to be quickly trained using small number of samples and the adaptation of the training model as the gestures are performed repetitively(Gillian, N., Knapp, R.B. and O'Modhrain, S. 2011, p.1).

To interact with the machine, the positions of the hands in space were used to perform the free exploratory movements in XY dimension controlling a pen and the data from the Classified gestures to associate specific auxiliary fixed operations such as drawing different geometrical shapes or to start or stop motion from the machine (Fig 30 - 32).

9 [http://www.nickgillian.com/papers/Gillian\\_ANBC.pdf](http://www.nickgillian.com/papers/Gillian_ANBC.pdf)



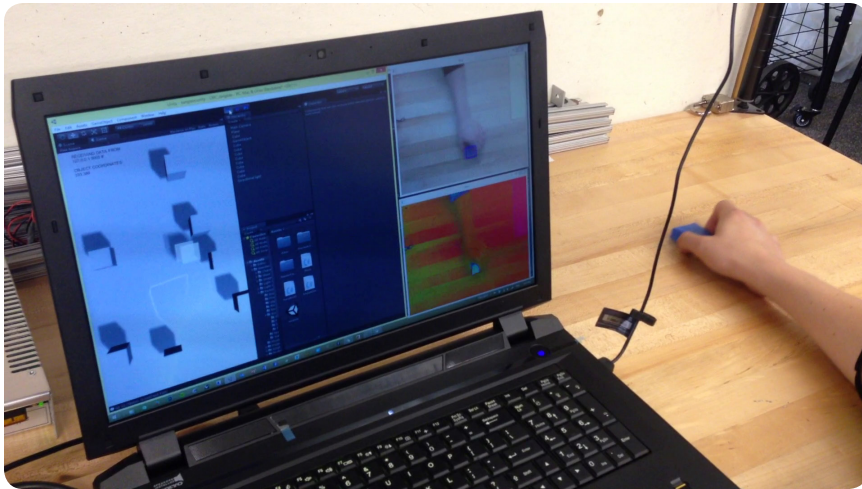


Fig 34  
Tangible Interaction

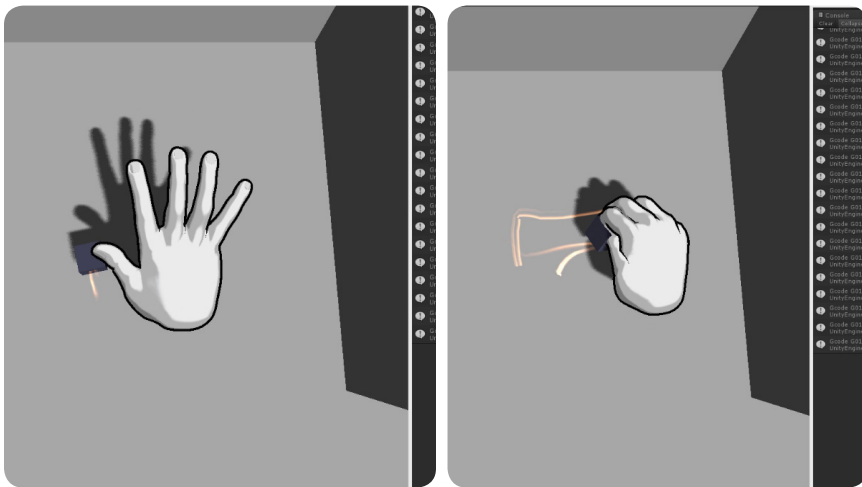


Fig 35  
Grabbing gesture  
recognition

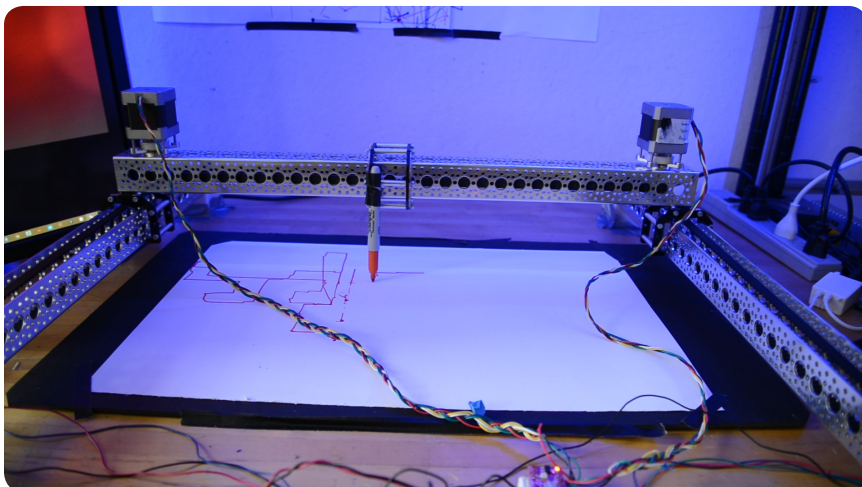
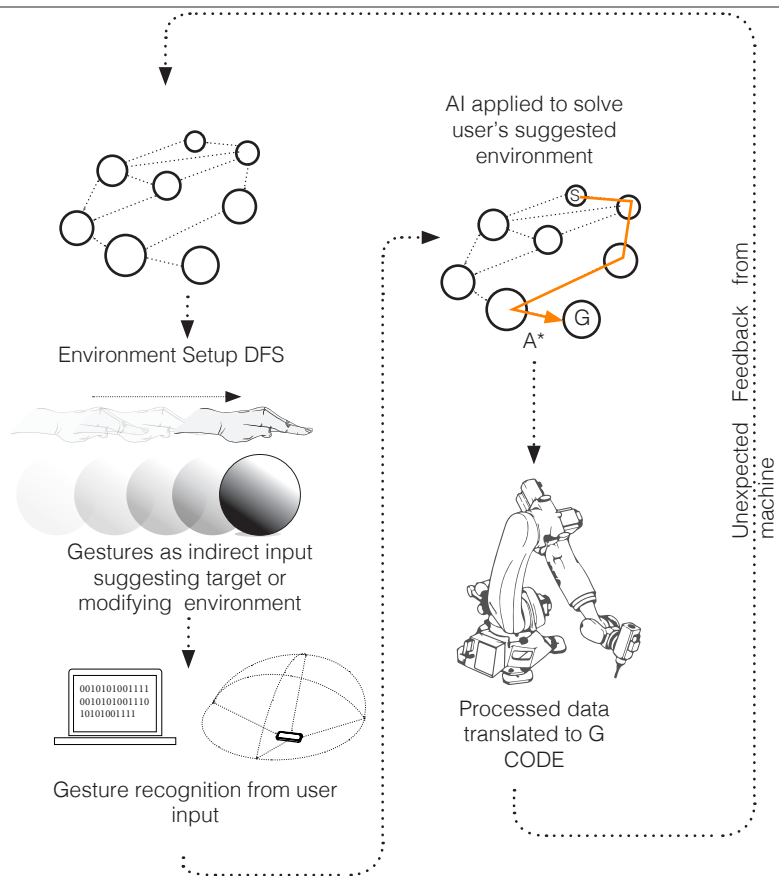


Fig 36  
Drawing output

Fig 37  
Collaborative interaction diagram



The implementation of gestural interaction was successful in order to enable the real time interaction that was intended with the machine. Moreover, the gesture recognition implementation allowed me to generate a workflow where the two types of movements (free and fixed) were successfully recognized and performed.

The implementation was done using Unity 3D and C# in order to visualize in a virtual environment the interaction with the machine.

### 4.5.2 Tangible interaction

A second type of implementation was the Tangible interaction(Fig 33). This implementation sought the development of a system based on the manipulation of physical objects in space in order to interact with the machine. By using computer vision algorithms such as object recognition -by blob, edge, and color detection- I was able to track the position of different objects to control the CNC drawing machine. By using OPEN CV<sup>10</sup> Library I was able to

10- <http://opencv.org>

---

recognize different physical objects and extract the position data to recognize the free and the auxiliary movements.

The idea of testing tangible interaction was to facilitate an indirect type of interaction considering haptic feedback (from the manipulation of physical objects) as an important part of the interaction process. By touching the objects manipulated the user could have a different experience than gestural interaction by touching the objects to produce motion on the machine. Combining the techniques developed from gestural interaction, using both webcam and Leap, it was possible to perform free movements of the objects in space in addition to the recognition of fixed movements such as grabbing an object to enable the motion of the machine while the object is manipulated (Fig 34 - 36).

If the implementation of the two the previous types of interaction were concerned with capturing user intentions by using gestures and physical objects in space, the main goal of collaborative interaction was the development a dialog where the machine could produce unexpected output and behavior according to what the designer proposes modifying a virtual environment using gesture recognition to get user input and Artificial intelligence as machine behavior (Fig 37).

In this case, the goal was to engage designer and machine in a collaborative design environment where the human is not concerned with producing a design -e.g. drawing- but with setting up an environment that indirectly influences the design by promoting the emergence of unexpected behavior and drawings from the machine to solve a problem. To achieve this goal, I implemented two different AI types of algorithms. First I used Depth First Search (DFS) to create a random environment as a maze. Later, I implemented an optimal search algorithm (A\*) to find a solution to the proposed environment as the machine behavior.

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### **4.5.3 Collaborative interaction**

Fig 38  
The machine solves the maze finding the optimal path to find the target

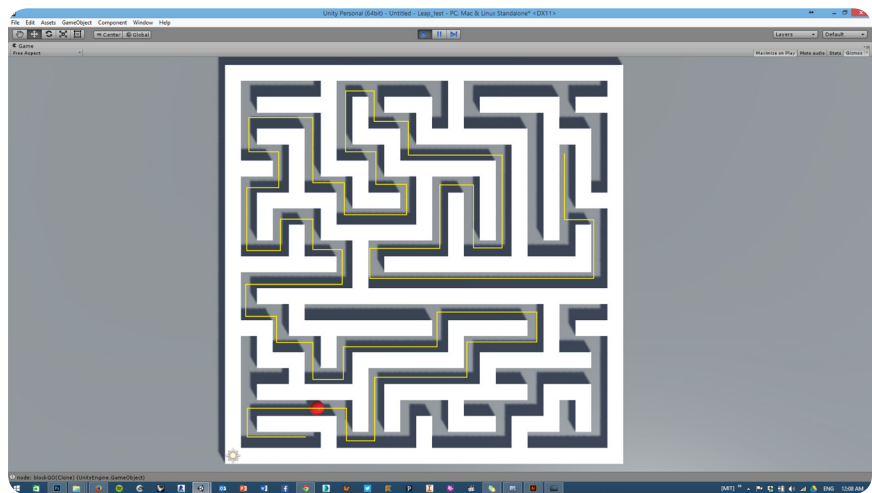


Fig 39  
The user through the use of gestures, modifies the environment or select a new target. The machine solves in real time the new optimal path to the target.

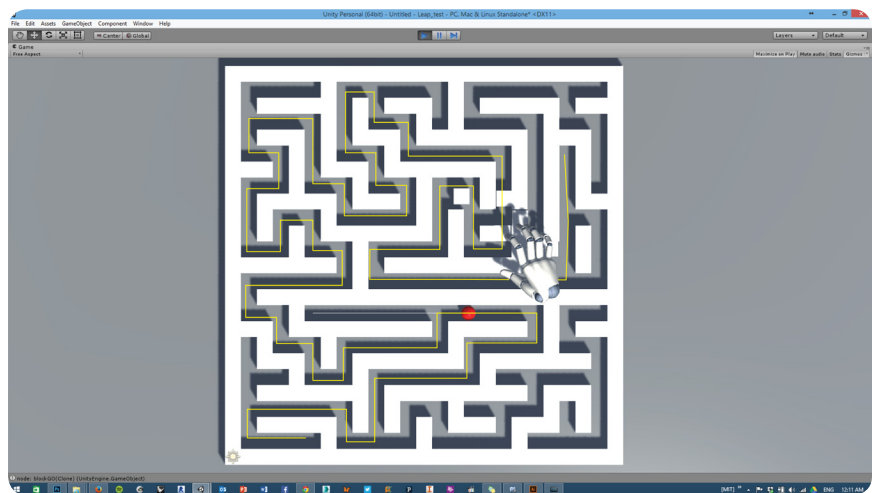
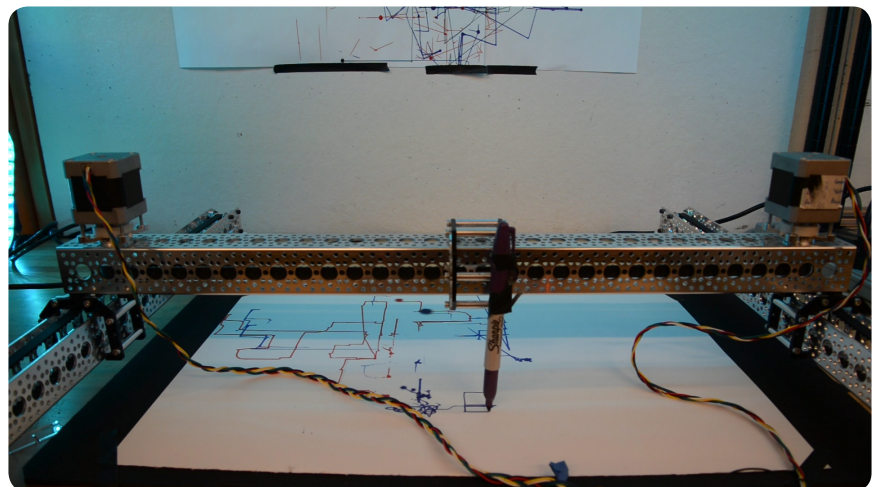


Fig 40  
The motion of the path is translated as GCode to the machine.



In this case, the human suggest a target point inside the Maze, and the machine should find the optimal path (using A\* algorithm) through the maze to reach that target. The path calculated by the machine to the target is then translated to machine's movements as G Code(Fig 38). Moreover, the software interface allows the user to specify in real-time -using gestures- a new target and/or modify the maze shape (by moving objects in the virtual environment). According to user input, the machine can recalculate on the fly the new path trajectory to the new target (Fig 39). In this case, is the user who generates indirect input so the machine through a constant recalculation of the maze solution -from its current position to the target- generates the motion expressed as drawings and unexpected behavior to the human user(Fig 40).

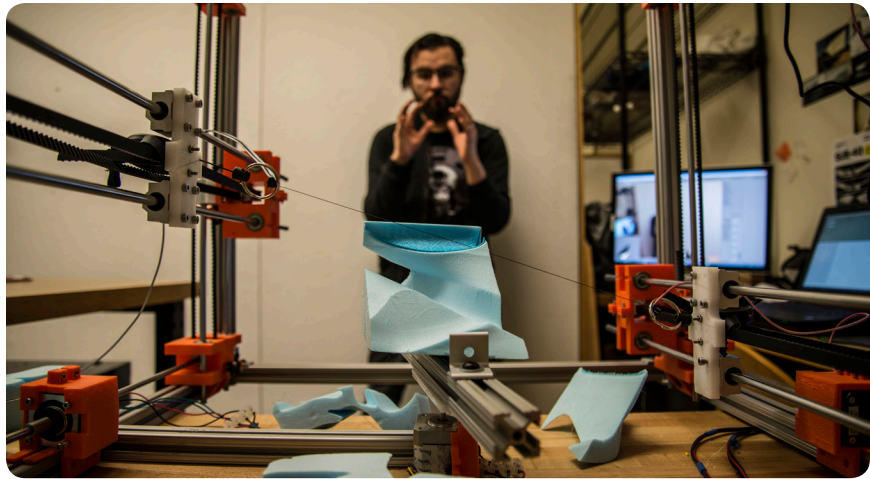
The implementations of different types of interaction were successful in terms of getting a fluid response from the machine according to designers gestures. In this case, the basic implementation of machine learning algorithms to discriminate the fluid exploratory gestures from the symbolic type of gestures (preprogrammed) served as the base to understand how the interaction with the machine should take place. Furthermore, it was clear that simple act of translating hands motion into XYZ coordinates into the drawing machine was insufficient in order to take advantage of the machine's characteristics. Moreover, in order to achieve a seamless interaction between machine and designer (as a transparent tool), the interplay between the fixed gestures -associated to fixed operations in the machine- and the free movements is crucial.

The development of the three types of implementations as separate models for interaction worked as the base for a more robust software improvement in the next stage of the project by integrating different technologies in a circular loop in capturing, analyzing and expressing the analyzed human gestures as improvisation as machine action.

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#### **4.5.4 Conclusions about experiments**

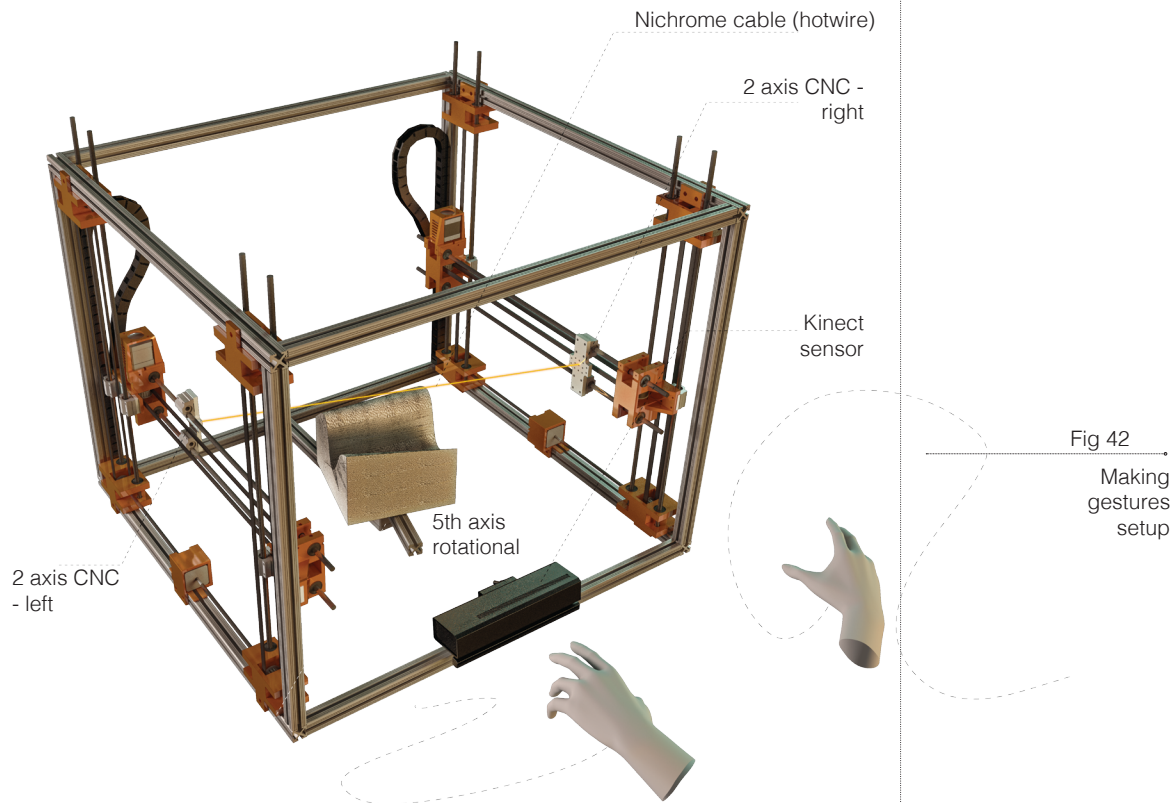
Fig 41  
Interactive design and  
fabrication system



#### **4.6 Making gestures: An interactive fabrication machine**

Making Gestures is proposed as an implementation of a new paradigm for the use of digital fabrication tools that integrates 'designer gestures' and the concept of 'tool embodiment' into the digital design and fabrication process (Fig 41). Specifically, the project was developed as a 5 axis hot wire cutter CNC machine that takes real time input from body gestures using motion tracking sensors in order to produce architectural designs and prototypes through improvisation.

Furthermore, this is a research project that inquires about new ways of 'designing' and 'making' by using hand gestures as a form of user input to interact with fabrication machines and create physical prototypes. Moreover, through the use of Interactive Fabrication Machines -imbued with artificial intelligence- the project aims to change the current paradigm present in digital design processes that relies heavily on 'tool operation' to a more fluid one based on 'tool interaction'. Through this real time interaction I add a new dimension of design and making present in analog design into the digital design process by capturing the real time contingency



between designers intentions, tools and materials behavior promoting the improvisational aspects of design (Fig 42).

With this project I attempt to prove that creativity and originality do not rely on the elaboration of pre-conceived ideas or plans, but on the relationship of perception and action as promoters of creativity and knowledge elicited, in which the concept of real time interaction through body gestures is the key to use digital tools in more creative ways.

The project was developed considering the implementation of the three previous projects in terms of hardware and software components. In terms of hardware, by the previous implementations of a 2 axis CNC drawing machine, I was able to determine the necessary components such as motion sensors, motion controllers, stepper motors and all the mechanical parts to design and build the 5 axis hot wire CNC system. The hardware design of the machine considered all the necessary factors in order to achieve a seamless interaction in terms of speed and response from the

#### 4.6.1 Hardware and software components

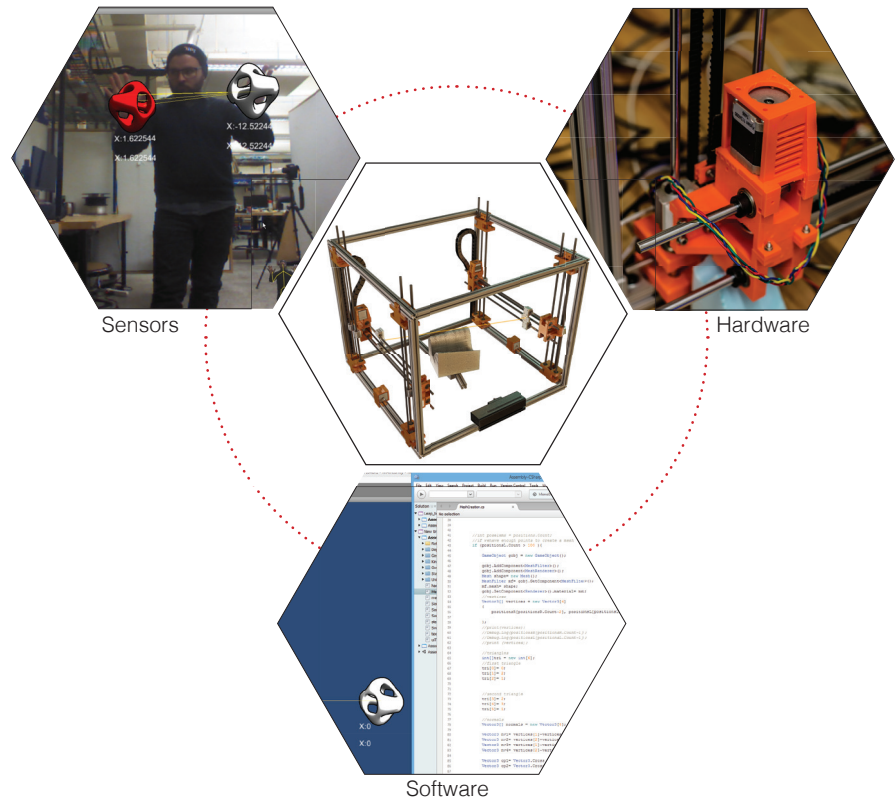


Fig 43  
Hardware and software components

machine, avoiding as much as possible the time delay between designer gestures and machine action (Fig 43).

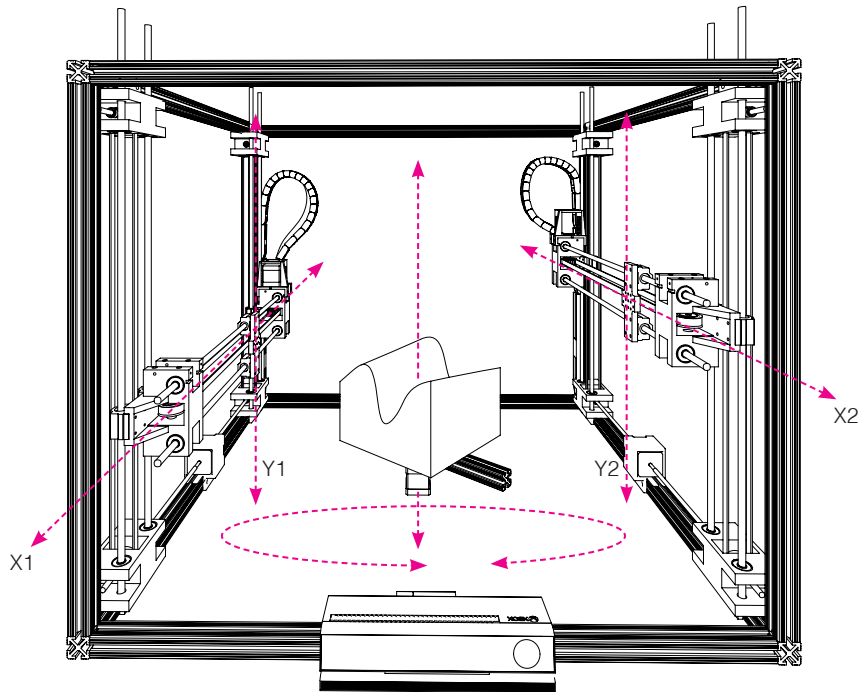
The machine was designed and built from scratch using aluminum profiles and plastic 3D printed parts to integrate the 5 axis system based on a timing belt motion system. I used a total of 5 stepper motors connected to a *TinyG*<sup>11</sup> controller board to control the motion of the 5 axis. All the system was powered using a 24v - 14a power supply. The system was designed as a double 2 axis system - one for each hand- attached to a nichrome electrified wire. A 5th axis was implemented as a rotary base to hold the Styrofoam blocks to be cut (Fig 44), adding one degree of freedom.

On the software side, in order to integrate the different technologies used to coordinate hardware components, sensors

11- TinyG is a 6 axis motion control system designed for high-performance on small to mid-sized machines. <https://github.com/synthetos/TinyG>

12- A Kinect sensor (also called a Kinect) is a physical device that contains cameras, a microphone array, and an accelerometer as well as a software pipeline that processes color, depth, and skeleton data. <https://msdn.microsoft.com/en-us/library/hh855355.aspx>





and data processing, I decided to use UNITY 3D game engine as development platform due to its robust graphic capabilities and its flexibility in terms of using C# as main scripting language to easily access and implement external libraries.

The main software was programmed using C# connected through UDP protocol to the Gesture recognition software (C++) and through serial communication to the Tiny G controller. For the motion tracking I used Microsoft Kinect for windows<sup>12</sup> connected directly to Unity 3D using Kinect SDK. The decision of using kinect over webcam or LEAP motion was taken considering the characteristics of the hardware in terms of flexibility (data gathered, platform compatibility), speed of tracking, accuracy of data and robustness of the SDK to perform a fluid interaction with the CNC machine. In order to interact in a more fluid way with the five axes of the machine, the need of capturing a full body skeleton in contrast to just an accurate hand model (LEAP Motion), was more important to implement a more natural interaction with the machine in term of body postures.

Fig 44

Diagram of the machine functioning

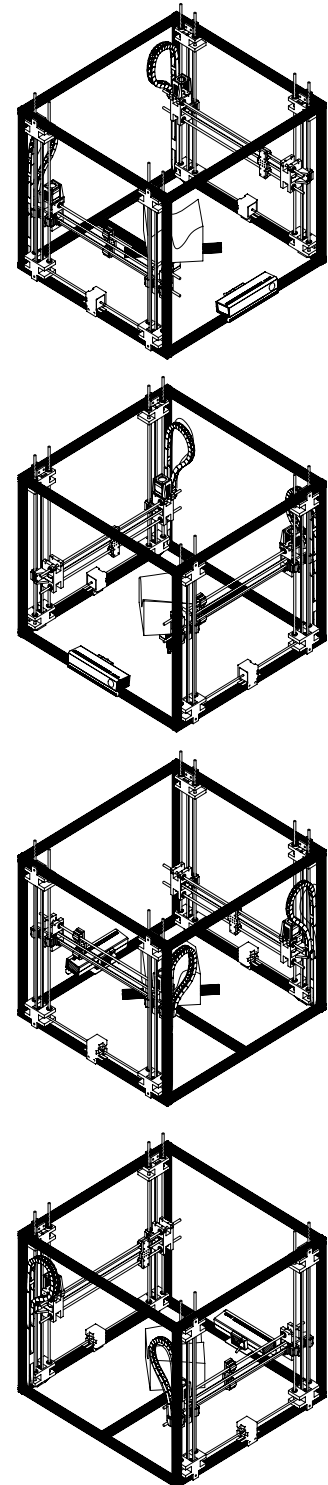
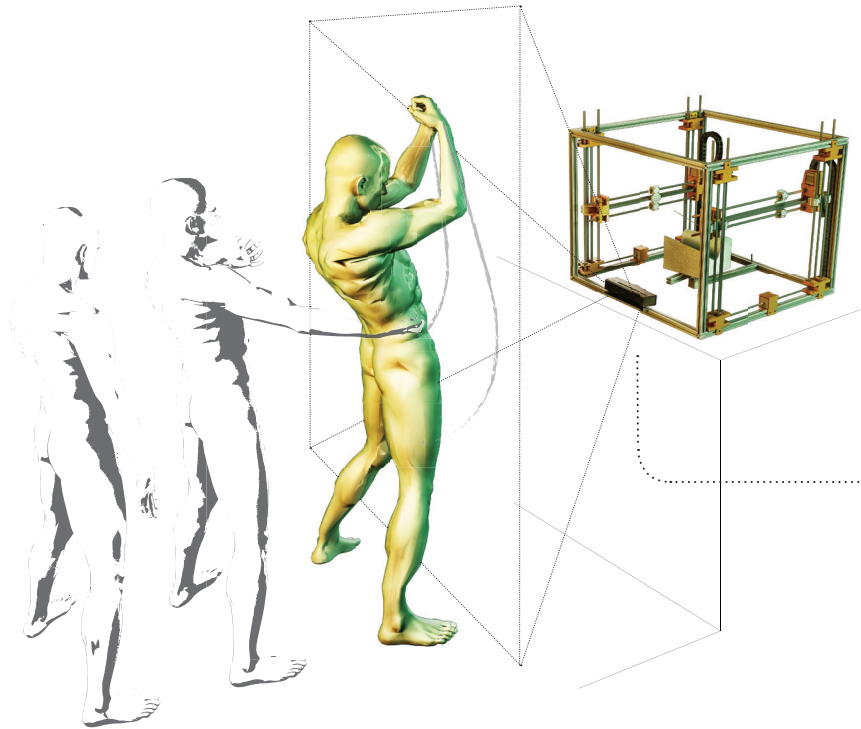


Fig. 45a  
Using the machine by performing gestures in a more natural way than just hand tracking in a limited space



#### 4.6.2 How the machine works

The interaction with the machine comprises two phases: Training and Making. In the training phase, the designer is encouraged to perform free movements to calibrate the machine in terms of speed, response and accuracy of movements. Moreover, in this phase of the interaction, the designer performs the training of the symbolic gestures that the machine will execute as fixed operations such as “start motion”, “stop motion”, “go home position” or implement specific fixed specific pre programmed geometric operations.

In the training phase, the utilization of machine learning algorithms is crucial so the software can gather the motion data form a skeletal model to extract the main features to perform the gesture analysis. Moreover, by using Kinect SDK, the software reads the created the skeleton model from depth map data and blob detection of the human. The skeleton model associated to an user ID, consists of several joints that have a position in space. The vector 3D data from the hands joints is used as features for the creation of the training model with the gesture recognition software(Fig 45).

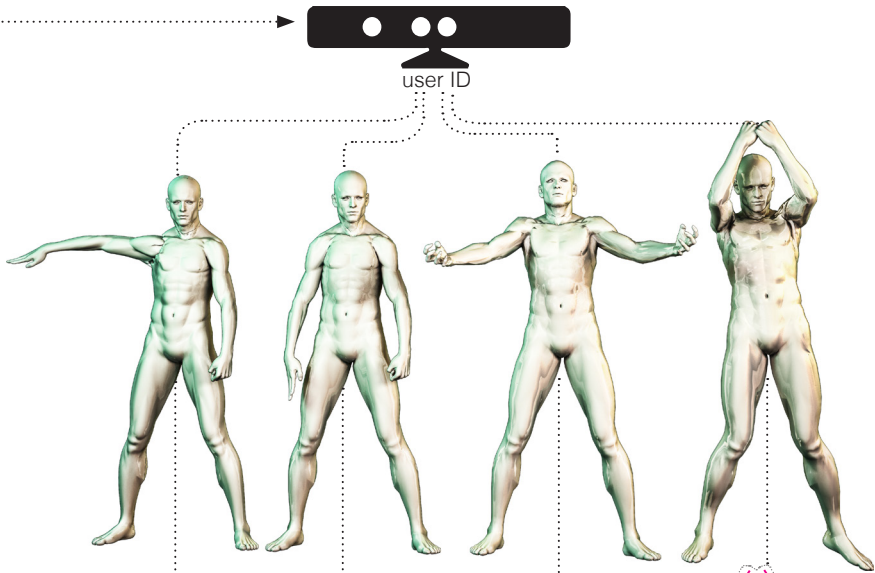


Fig 45b  
Gesture performance

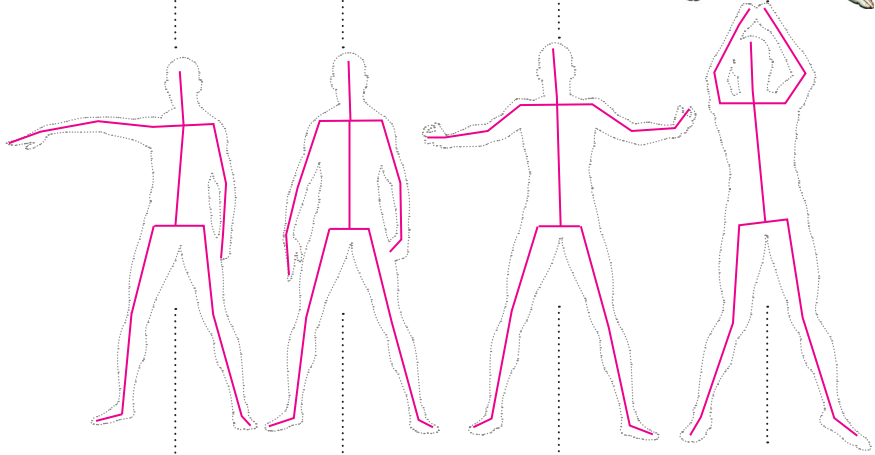


Fig 45c  
Real-time skeleton  
model according to an  
user ID

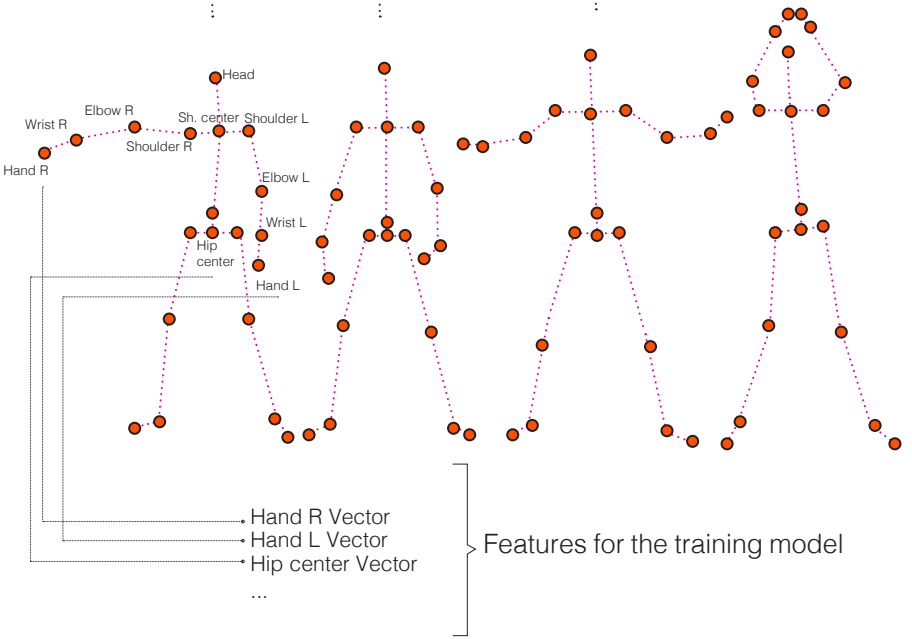
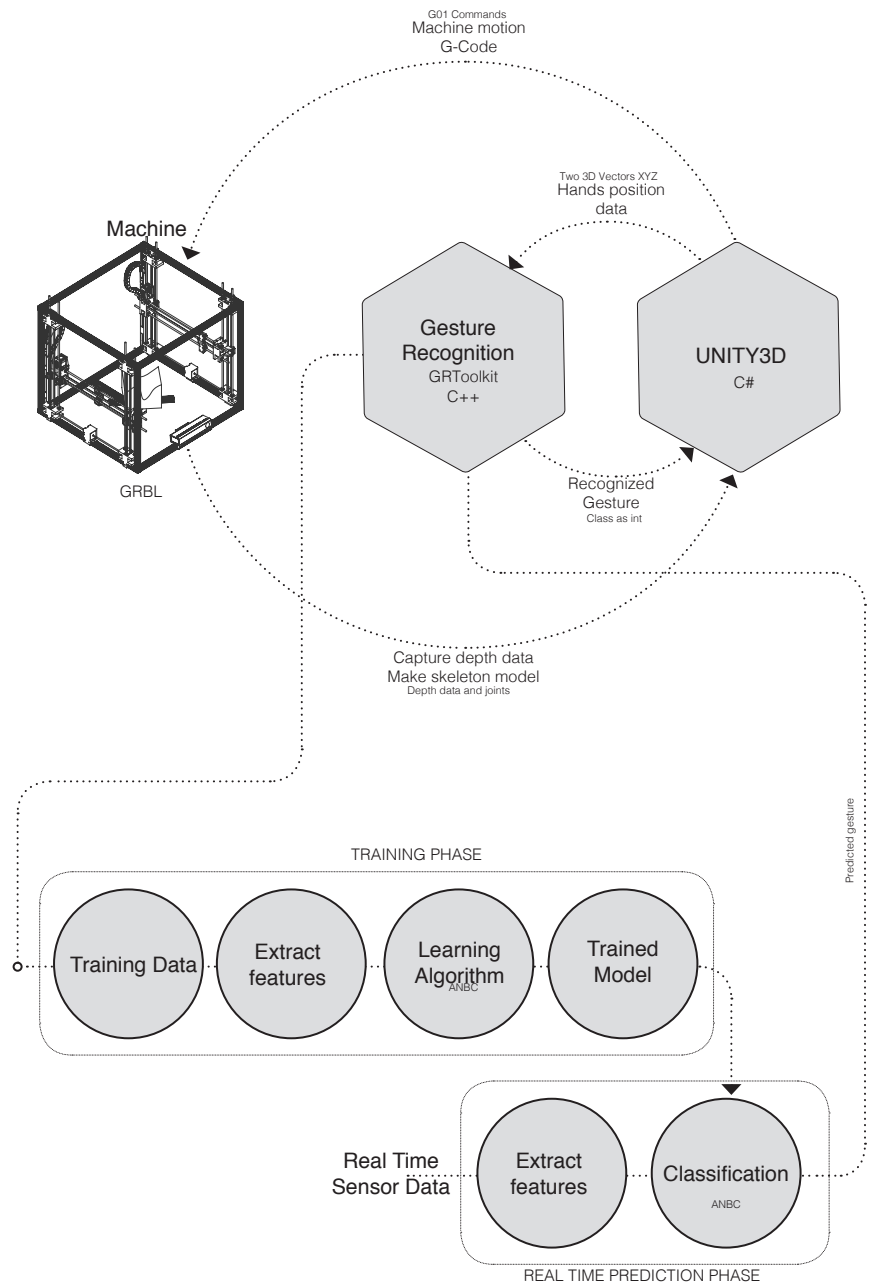


Fig 45d  
Joints detection and  
features extraction

Fig 46  
Data flow between hardware and software



```

//Create the main variables
ClassificationData unityDataTrain; //stores training data
ofxOscReceiver UnityListener; //OSC listener for unity messages
GestureRecognitionPipeline GRpipeline;

//
^
^
//Setup the training data
unityDataTrain.setNumDimensions(6); //set the dimansions XYZ of the training sample for each hand
trainingModeActive = false; //boolean value set to true when training
predictionModeActive = false; //boolean value set to true when predicting
trainingClassLabel = 1; //changes when we train a different gesture
^
^
//Setup the classifier
ANBC anbc; // create a adaptive naive bayes classifier
anbc.enableNullRejection(true);
anbc.setNullRejectionCoeff(5);
GRpipeline.setClassifier( anbc );

// OSC from unity
while(UnityListener.hasWaitingMessages()){
    // obtain next message from unity
    ofxOscMessage unityMessage;
    UnityListener.getNextMessage(&unityMessage);

    vector< double > inputVector(6);
    sample[0]=sample.unityMessage.getArgAsInt32(0); //x position Left
    sample[1]=sample.unityMessage.getArgAsInt32(1); //y position Left
    sample[2]=sample.unityMessage.getArgAsInt32(2); //z position Left
    sample[3]=sample.unityMessage.getArgAsInt32(3); //x position Right
    sample[4]=sample.unityMessage.getArgAsInt32(4); //y position Right
    sample[5]=sample.unityMessage.getArgAsInt32(5); //z position Right

    if( trainingModeActive ){
        if( trainingTimer.getInRecordingMode() ){
            unityDataTrain.addSample(trainingClassLabel, sample);
        }
        if( trainingTimer.getRecordingStopped() ){
            trainingModeActive = false;
        }
    }

    if( GRpipeline.getTrained() ){
        if( !GRpipeline.predict(inputVector) ){
            strOut = "Failed to make prediction";
        }
    }
}

```

Fig 47

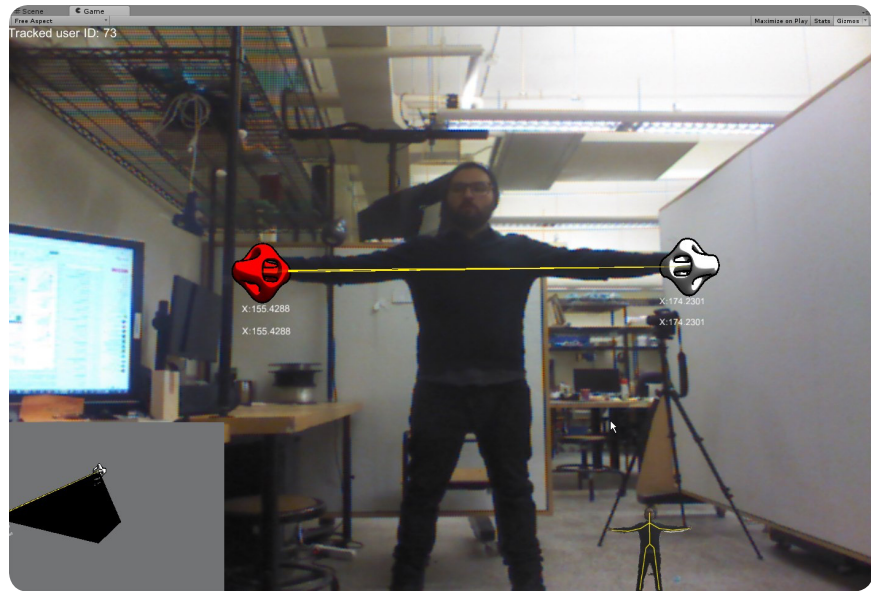
Code fragments of basic functioning of GRT through OSC

Data recording + training

Furthermore, by repeating a specific gesture, the data extracted from the skeleton's joints is transmitted through OSC to the Gesture recognition software (programmed in C++), which takes it as a 6 dimensional vector (3 dimensions for both hands) adding it to a trained data file as positions related to a specific class (gesture). Moreover, the data file is pre processed extracting the features and a learning algorithm is applied (Adaptive Naive Bayes Classifier) in order to recognize the class being performed (Fig 46). For experiment purposes, each class is trained with an average of 1000 data samples which are enough to perform analysis and further prediction during the use of the machine. Finally, after the training model is created, the software is ready to perform the real time prediction phase which in this case happens in the act of interaction with the machine by the designer (Fig 47).

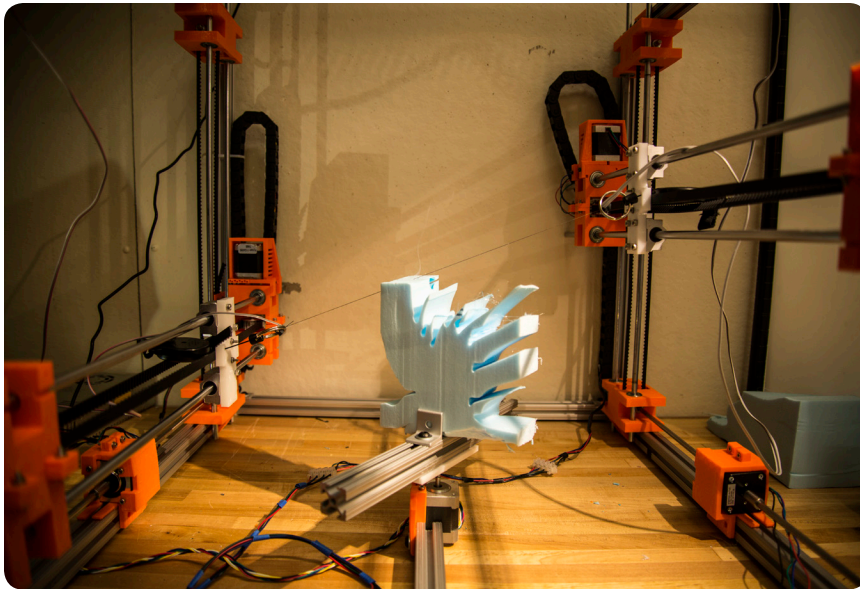
After the training model is processed, the software allows the implementation of fixed auxiliary movements associated with the predicted gestures. As stated previously, the use of auxiliary fixed movements, facilitate a better integration in terms of controlling aspects of the machine that are constant in the act of performing

Fig 48  
 Training phase: on screen  
 visualization of user gestures  
 tracked.



fabrication operations such as “engaging motion” “stop motion” , “homing” or “rotate 5th axis in x degrees”, or even performing pre defined geometric operations (Fig 48).

In the making phase, the designer is concerned with designing and making through improvisation. Moreover, is in this stage of the project where the full integration between human and machine happens. Through the use of designers gestures, the machine interprets the data and is able to determine from free improvisational and fixed auxiliary movements. Is after the training stage that the machine is capable to cope with the designer intentions as gestures, since is calibrated to respond and behave according to the designers uniqueness. The goal of the project implementation as an interactive machine, is to prove that creativity emerges in the very moment of impression of the self onto the material world as an **improvised choreography** between humans and objects (materials and tools) **by using body gestures neither as action nor perception, but as the unity of both.**



After the assembly, programming and calibration of the machine was done, I conducted a series of tests with users in order to test the integration of the different hardware and software components in the act of making foam prototypes (Fig 49).

The main goal was to test the hypothesis about the development of a system for design and fabrication in real time where the transition of idea to prototype happens instantaneously. Moreover, the goal was to test how the designer integrates with the technology in order to improvise in a more fluid and natural way without dealing with peculiarities outside the experience of designing and making.

In Addition, the experiments comprised at the beginning a total freedom for exploration, in order to get their opinions and feedback in relation to:

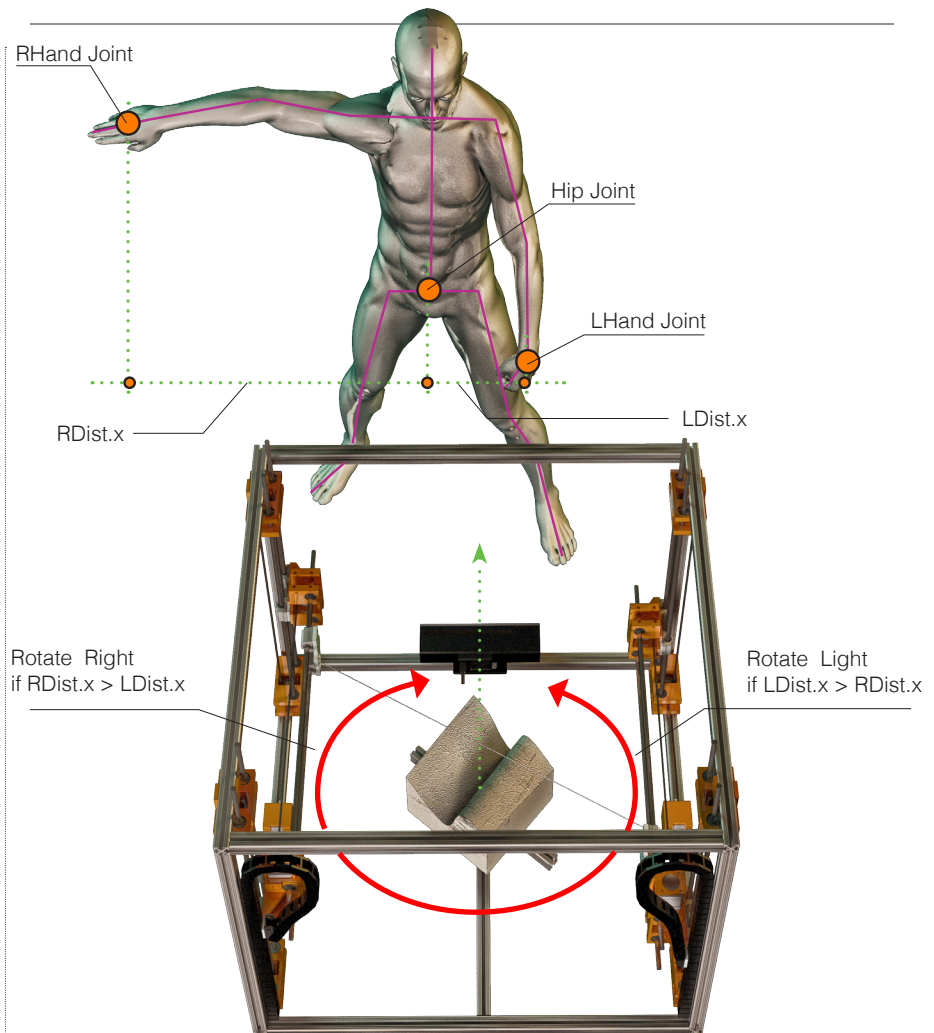
- How integrated and natural to use was the tool in terms of gestures and machine motions.
- How does the machine represent an alternative way of using technology in design to explore and improvise instead of just representing.

### 4.6.3 Experiments

Fig 49

The machine and prototype.

Fig 50  
Rotational movement in relation to body action



#### 4.6.4 Free exploration and adjustment phase

The first stage of the experiments contemplated the free exploration of forms from the participants. Moreover, by using the machine for short periods from 10 to 15 minutes, the users were able to train and get familiar with the machine in terms of machine motion and response.

By conducting the experiments, It was noticeable that the most difficult aspect to control was the rotation of the fifth axis, since it represents an indirect spatiotemporal relation between the action of the gesture and the corresponding action of the machine. In this case, while the motion of the hot wire is controlled by hands movements in Y and Z local parameters of each sides (fig 50), the control of the rotational axis is controlled by the x parameter of each hand. This rotational parameter is controlled taking into consideration the x distance from each hand to the hip joint of the



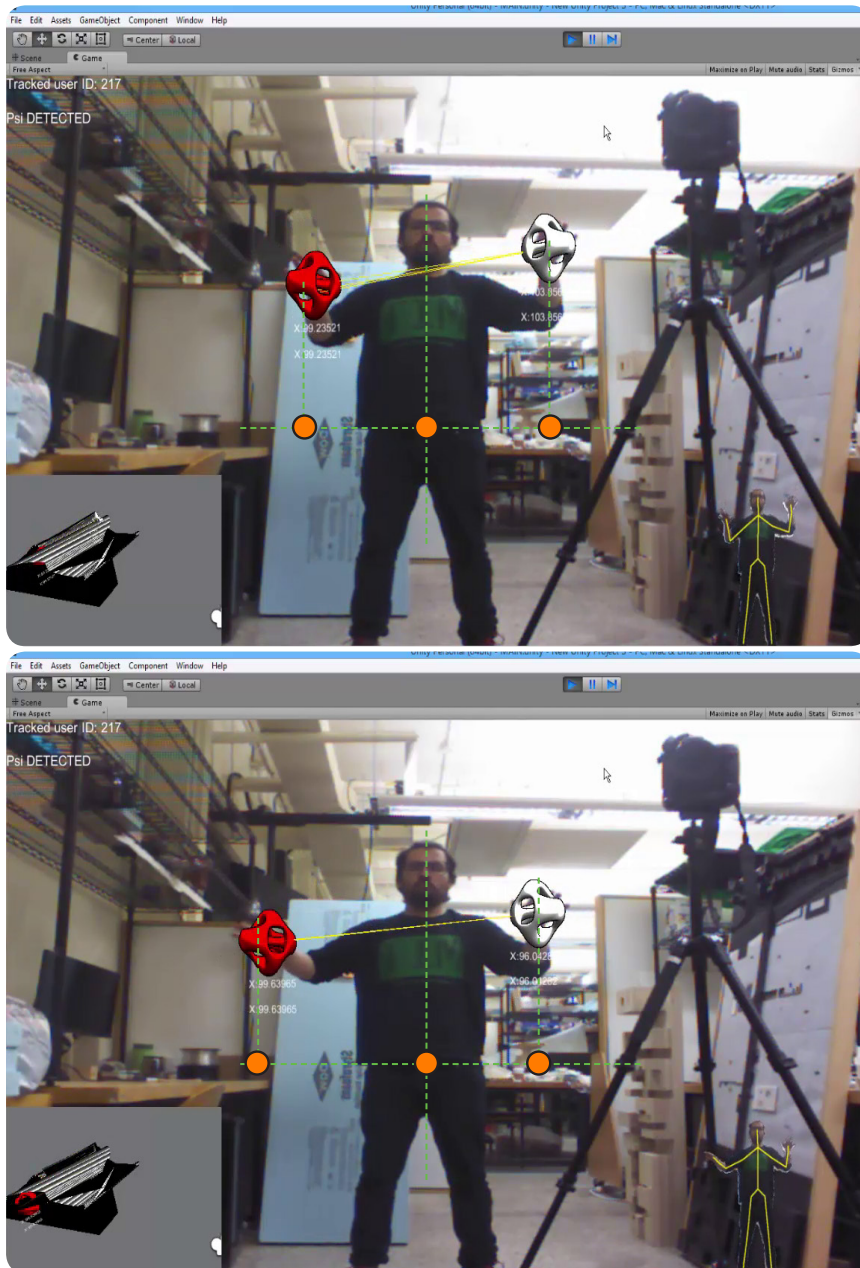


Fig 51

Performing a gesture to rotate the 5th axis to the right.

tracked skeleton.

The software measure both distances and determines which one is greater within a tolerance factor. For example, if the distance from the hip joint to the right hand is greater than the distance from the hip joint to the left hand, the machine rotates to the right in x units, and vice versa (Fig 51).

In terms of user responses to the machine, this stage of the

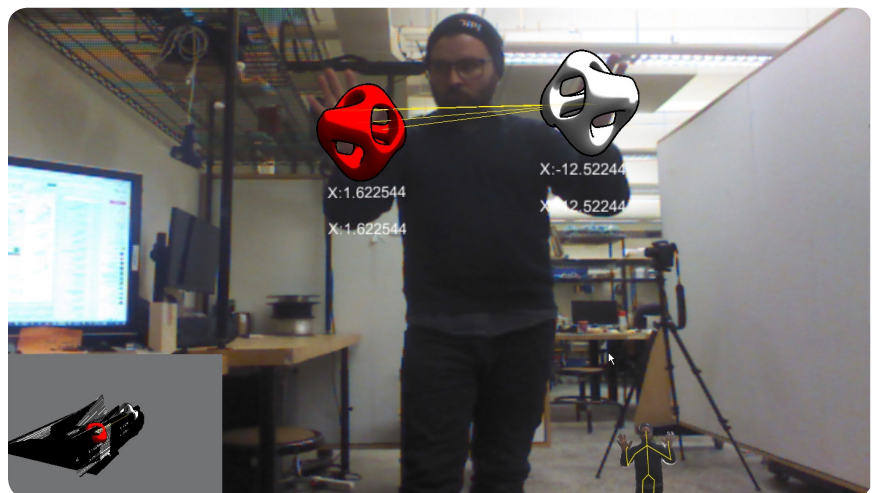
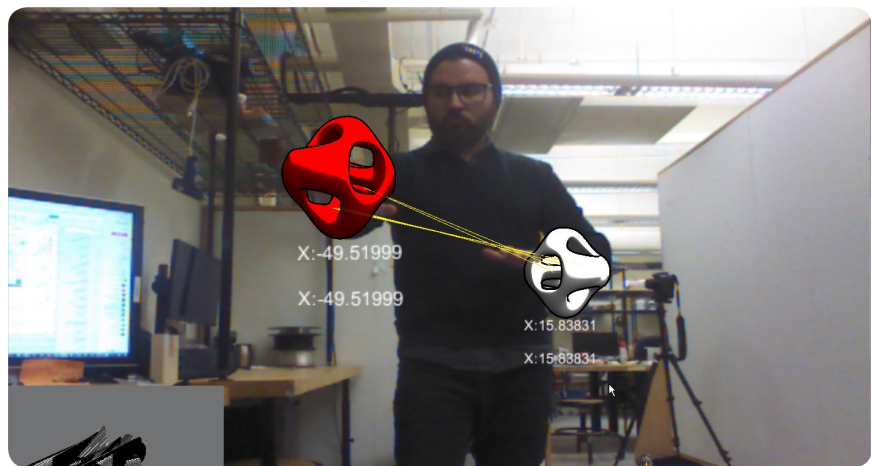
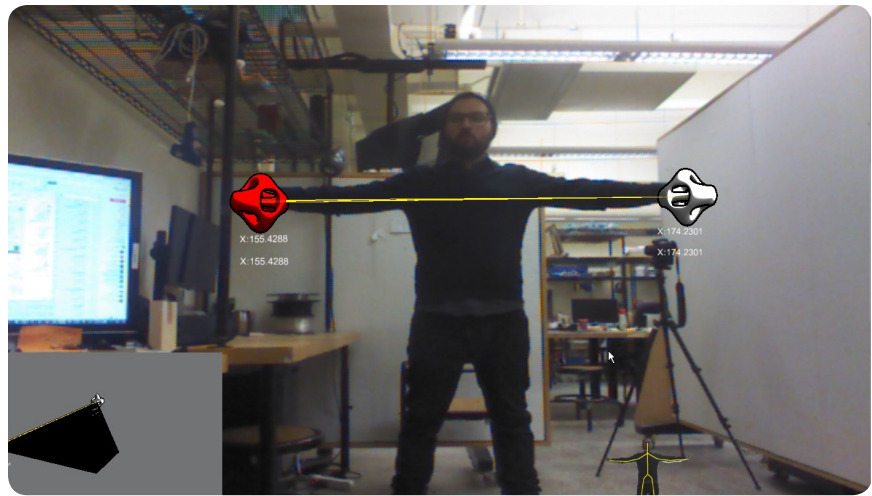


Fig 52  
Free exploration and  
machine adjustment

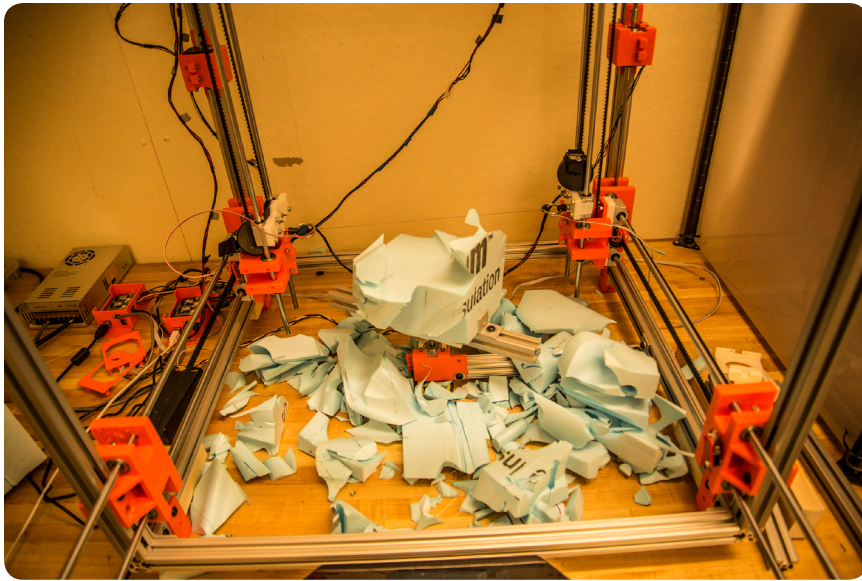


Fig 53

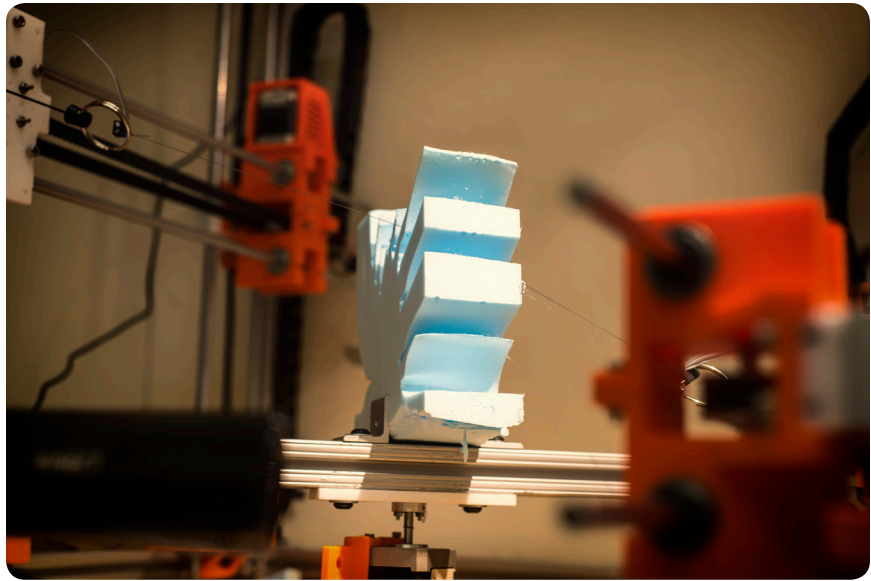
First outcome from the adjustment phase

experiments was crucial to determine other important factors such as delay between gesture performed and movement executed in the machine. In this case, it was possible to adjust the settings of the electronic components so the machine can respond in a very precise and fast way to user's gestures (Fig 52).

Finally, the testing period was essential to demonstrate that after a period of reciprocal adjustment between designer and machine ,

Fig 54

Machine and  
prototype detail.



the work flow and conversation was concerned within the sphere of interaction possibilities and feedback between both sides. After the designer is able to master the motion of the machine through gestures, is that the tool becomes internalized as a transparent technology. In most of the cases, the adjustment period resulted in random shapes that emerged as the result of the designer getting use to the machine (fig 53 to 57).

Several trials were performed with different users in order to prove the functioning of the machine as an interactive design and fabrication tool (Fig 58). The tests considered different exercises such as making a simple curvature surface, a double curvature surface, a parallelepiped, and free form exploration (Fig 59). Furthermore, the results from those tests showed interesting outcomes in terms of visual and aesthetics since no form was perfectly executed according to tool, material and human response. The 'imperfect' shapes emerged as interesting approaches to discovering new things while the designer attempts to make or replicate a specific shape.

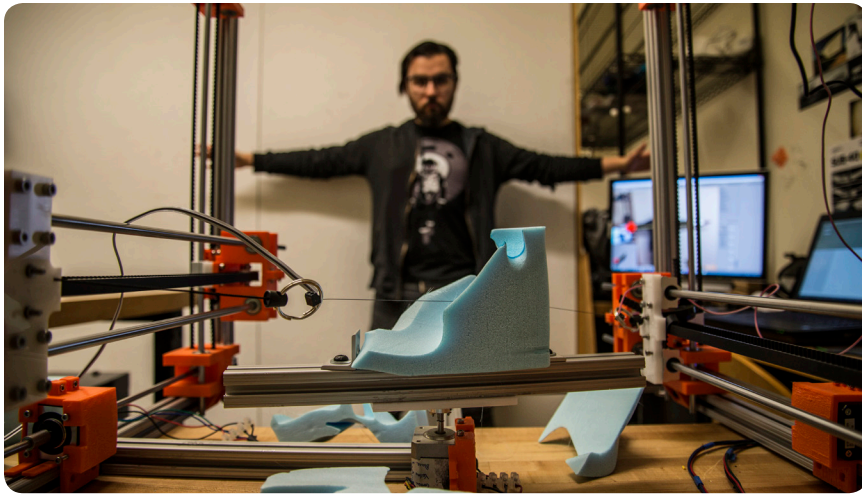


Fig 55

Start motion gesture

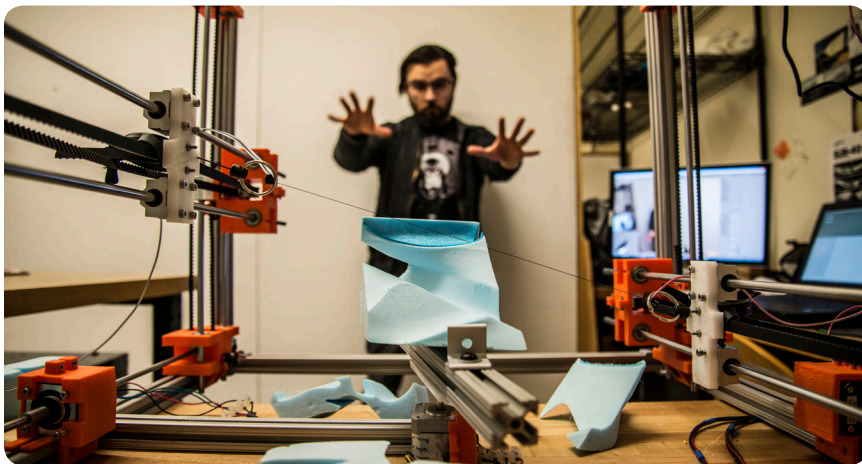


Fig 56

Hold position gesture

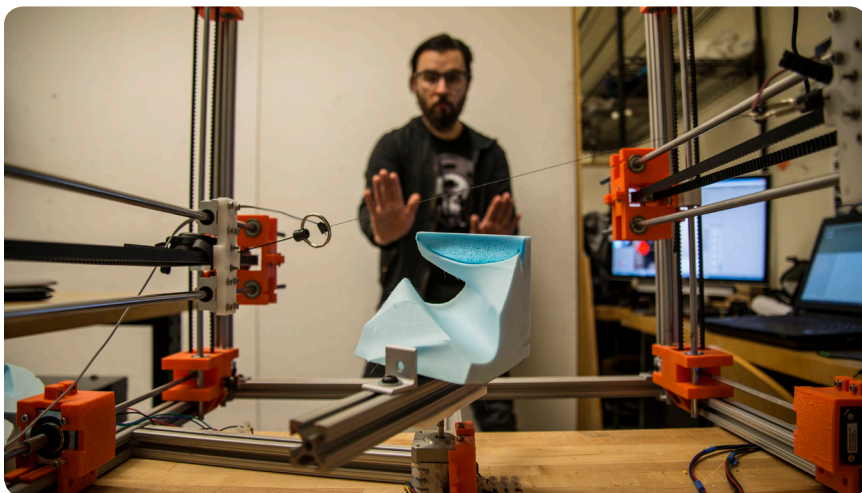


Fig 57

Free movement gesture

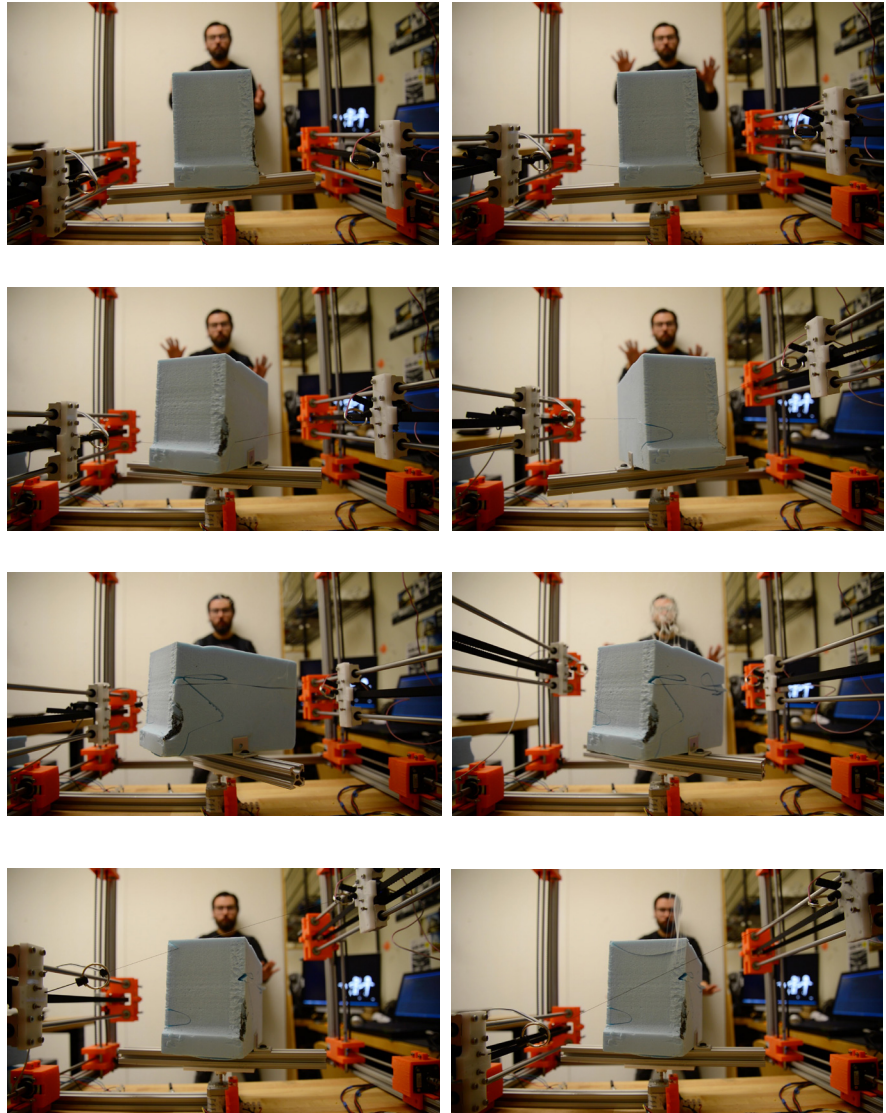


Fig 58  
Making image  
sequence

As an example, two users were requested to make a cube using the machine (Fig 60). The results from the experiment were very interesting in terms that the outcome was very different on each case. Moreover, if well the figures can resemble a cube or at least to a parallelepiped, in detail both shapes are very different from each other. Furthermore, that is exactly what the purpose of the implementation of the Making Gesture is. The physical manifestation of the idea of a cube in each case - beyond aspects such as familiarity with the tool in time - are very different mainly because the way those cubes were made happened in a total different way in terms of gestures, order of slices, how the piece was rotated using the fifth axis, and so on.

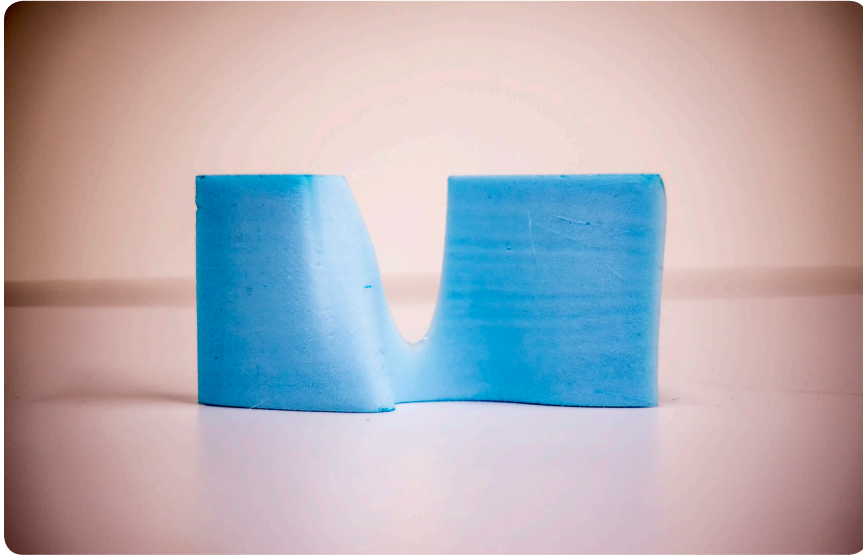


Fig 59a

Simple curvature shape

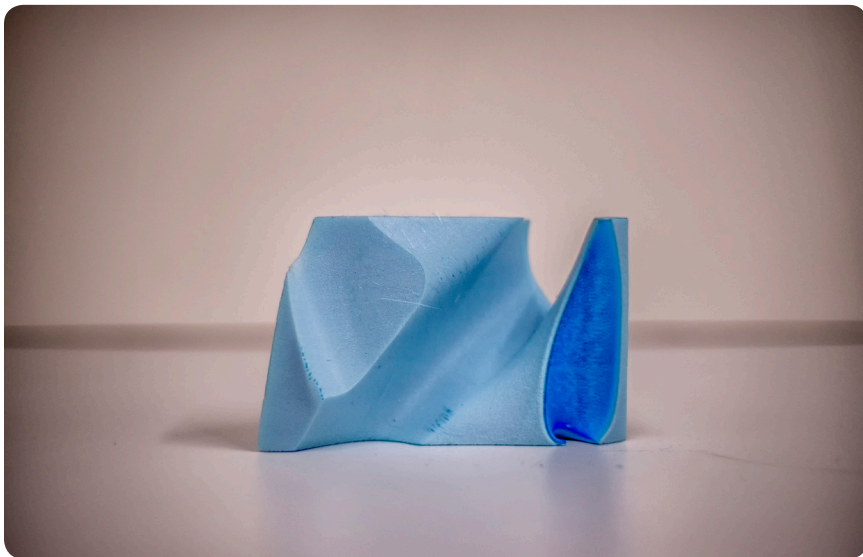


Fig 59b

Double curvature shape

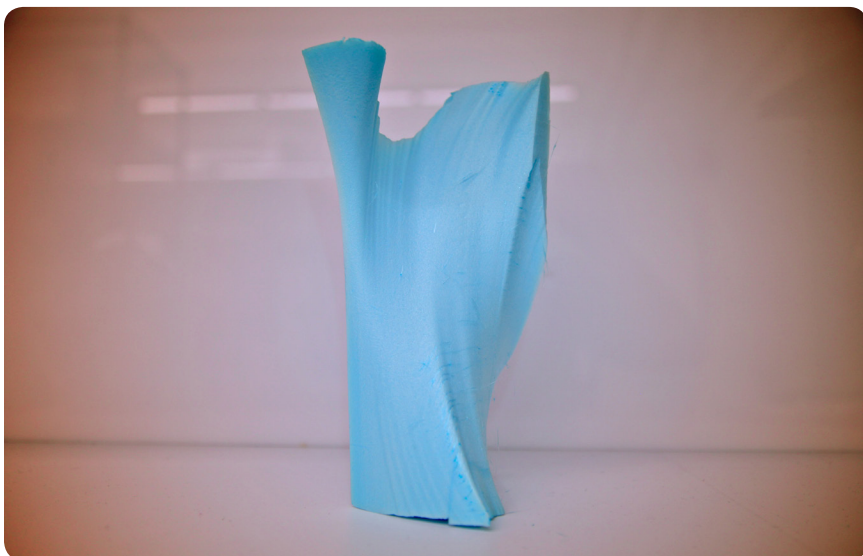


Fig 59c

Free Exploration shape

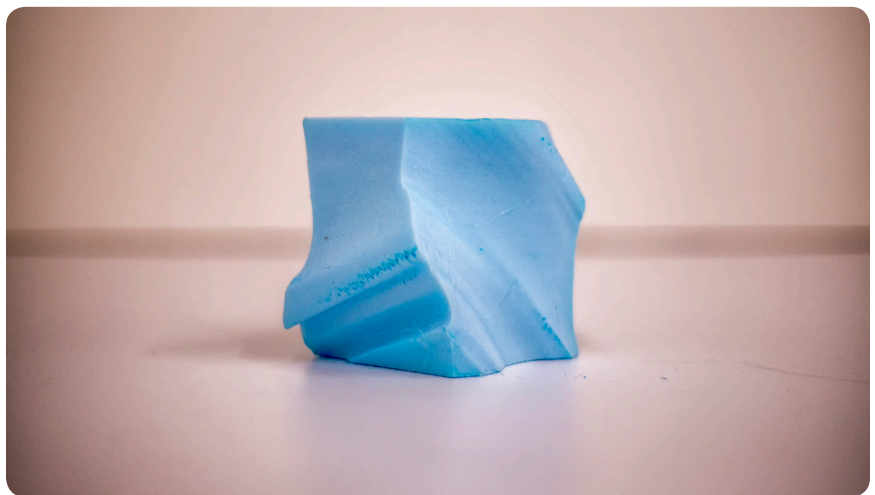
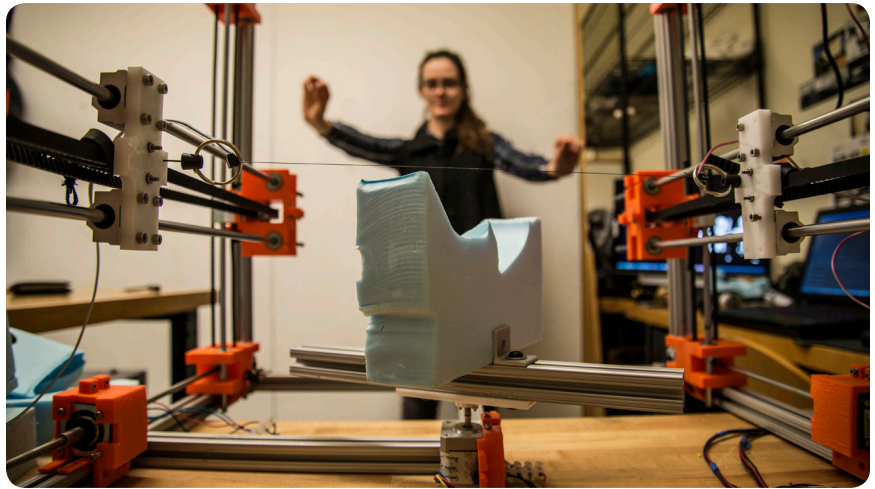
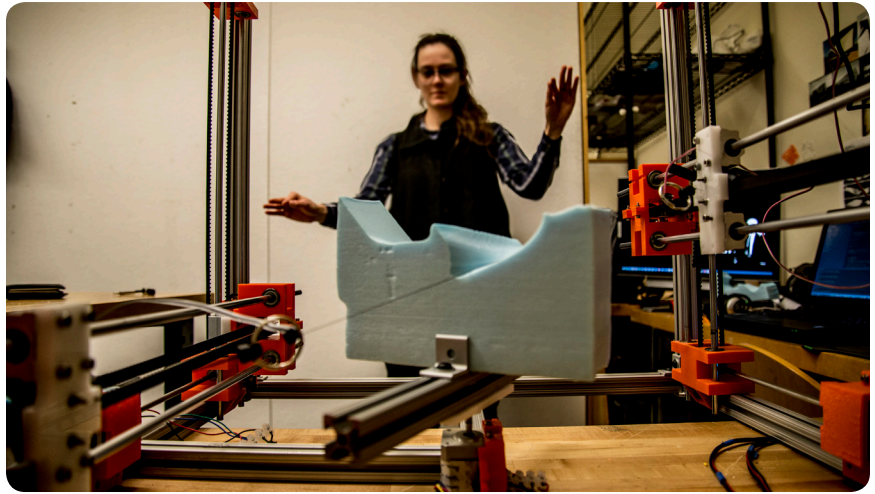


Fig 60a  
Making a cube shape 1



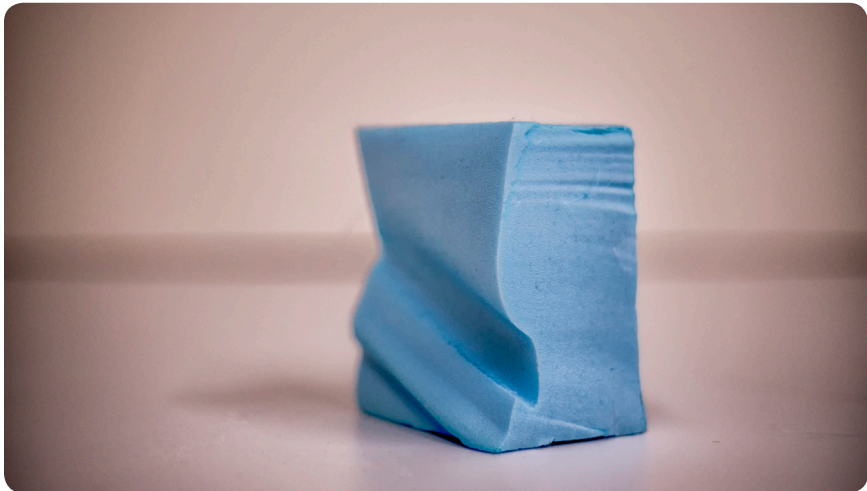
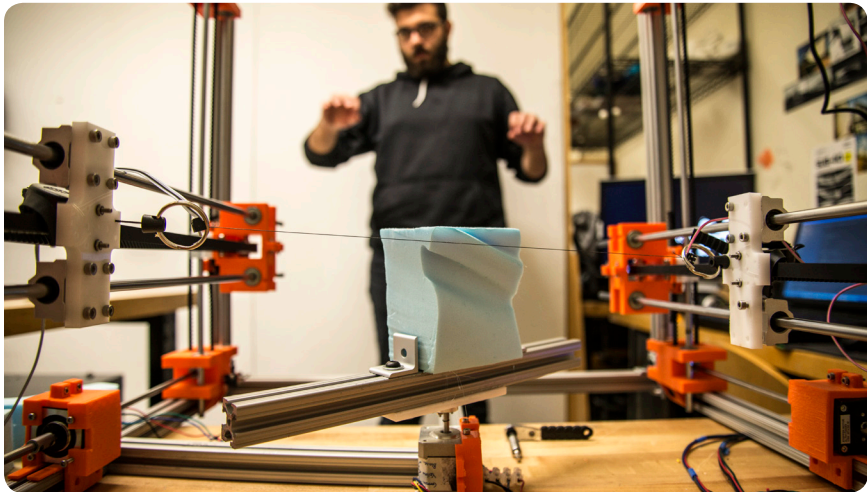
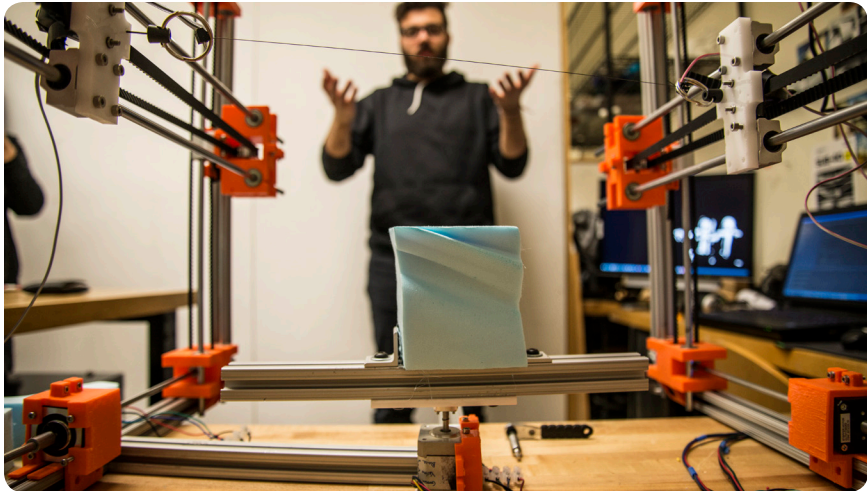


Fig 60b  
Making a cube shape 2

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#### 4.6.5 Experiment findings

The manifestation of 'a cube' is no longer determined by perfect linear trajectories of the hot wire to perform a 'clean cut' but by the ever changing conditions - visual, material , psychological and so on- of the moment the designer who is aware of things as he or she see and makes on the fly.

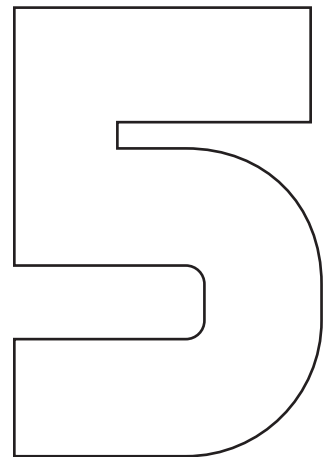
By testing the machine with different initial goals, I demonstrated one of the most interesting points of this research related to embracing and incorporating "error" as a positive aspect of the design and making enterprise. Current digital design tools -hardware and software- by applying a set of translations in order to bridge idea and prototype, neglect error as an intrinsic characteristic of the design process. Moreover, I assert that error and imprecision could be the base not only for improvement of designs in a technical way but also as a learning process where the designer learn form mistakes.

The application of this type of machine aims for recovering error as the base for producing the new and unseen every time we attempt to perform a design. Is by performing designs that we can engage in a more active way with our creations as something unique by capturing the moment. As Stiny(2006) argues *"What you see and what you do belongs only to you -it´s always your own work. There´s something new and original every time you look, and who knows, the results may be spectacular"* (p.386)

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# Conclusions

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## 5.1 Conclusions

In the development of this thesis, I provided a novel approach to design and fabrication by exploring real-time interaction between mind, body, and digital tools. Moreover, by using body gestures and imbuing fabrication machines with behavior, my goal was to establish an interaction that embraced ambiguity and the unexpected engaging the designer into more improvisational and insightful design processes.

Through the theoretical discussion, I was able to demonstrate that we must move toward more reciprocal processes integrating digital tools, not only by focusing in the creation of plans for representation, but on models for interaction embracing the perceptual and actional aspects of creative processes to reconcile 'design and making' as an embodied activity. Furthermore, I have introduced the idea of real time performance in fabrication through the Making Gestures project, in order to reconcile design and making transcending from an operational model of designing through technology, towards a more reciprocal way of computational making. Through this project, I argued that creativity emerges in the very moment of impression of the self onto the material world as an improvised choreography between humans and objects -materials and tools- by using body gestures neither as action nor perception, but as the unity of both.

By developing a series of different experiments I was able to provide as empirical evidence of the work, a model for interaction in design and fabrication that sought the seamless integration between designers and fabrication machines in order to solve the problems initially identified in this research. In the first place, I have demonstrated that, by using design and fabrication

machines imbued with behavior performing in real time according to designer's intention, the problem of black-boxing can be avoided. Moreover, by making tools capable of becoming transparent and internalized, the designer can focus and concentrate on the design and making in a similar analog tools are used. I implemented a system that doesn't focus in the manipulation of intermediate artifacts to translate an intention into material but in one that participate seamlessly in a dance of agencies of designer, tools and materials.

As a consequence of this seamless integration between designers and tools, I solved the creative gap. Because the system is interactive and dynamic, capturing and performing according to the specific resistances and contingencies of participants, tools and environment, there is no gap between idea and designed object. The system eliminates the multiple translations present in digital design and fabrication processes so the designer can focus on the act of creation by seeing and doing/making in real time.

Finally, the system solves the problem of the generic outcomes, by allowing the impression of the self onto our material world since it captures designer's gestures and translate them as intentions in real time to the material, starting from the argument that the originality and the creativity emerge from the fact that no gesture is same as other, mainly because of the ever-changing properties and characteristics of the participants (material, visual, psychological) in this interaction.

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## 5.2 Contributions

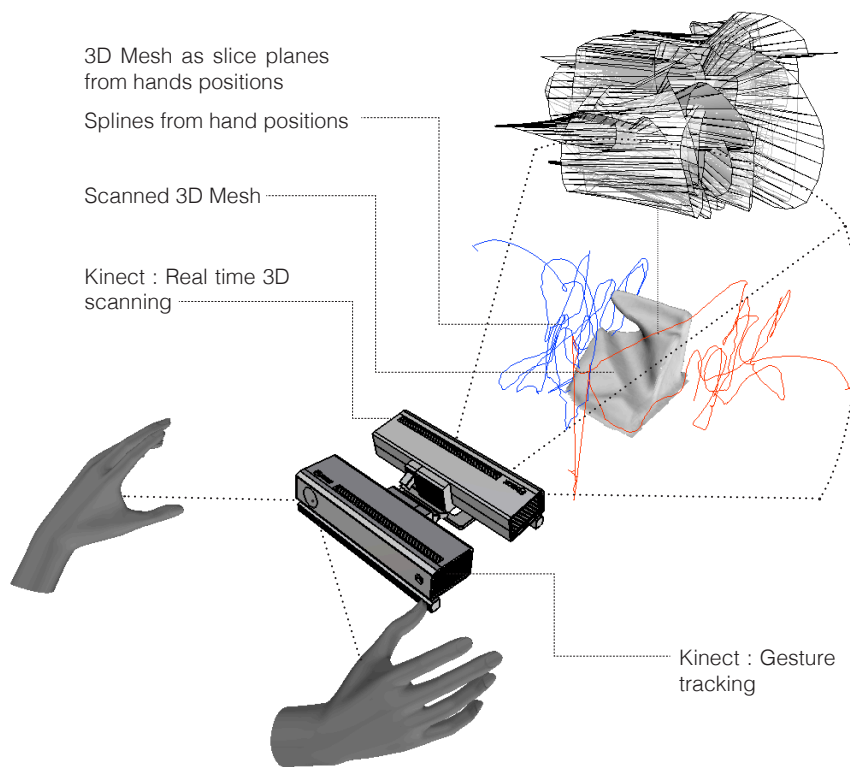
As contributions, through the development of this thesis, I was able to expand the discussion of using technology in design in a more creative way towards other fields such as psychology anthropology and cognitive science , finding answers and evidences on why the problems addressed in this research are relevant for architecture , design and computation.

Making gestures was created as a model of interaction with design and fabrication machines, by which I sought to contribute to the design and computation field by the development of a framework for action in real time with digital tools, in contrast to one focused in the development of plans for representation. Moreover, another contribution is the one related to reconciling design and making through improvisation with computational tools developing a system capable of capturing error as a positive characteristic in order to discover new and unseen things in design.

In the digital fabrication field, the gesture based CNC machine is a contribution since its proposed and implemented as a human centered system, capable of grasping the uniqueness of designer by capturing and interpreting gestures through machine behavior using artificial intelligence.

Finally, because the successful integration in terms of hardware ad software into a fluid design and fabrication machine, the system is capable to be scaled and extrapolated to many design scenarios such as Pedagogy, Art and the Building Industry.

Making Gestures is the initial step to develop a better integration between designers and tools in order to promote the very aspects that make design an original and unique experience every time we create something.



## Future Work

Fig 61  
Diagram of data collected by Making gestures project

More work is needed in order to keep developing this project to further steps of implementation. Moreover, improvements in mechanics, electronics and coding are crucial to take this project to better applications in the field of design and architecture. The consideration of further development starts by the possibility of using the data gathered by the KINECT (Fig 61) in order to expand the project scope to other applications.

By taking advantage of the scanning 3D capabilities of KINECT sensor, one specific implementation is to get a 3D model of the prototypes created in order to get a digital representation of the design for documentation or learning purposes. Furthermore, if this project is related to cognitive aspects of the design process, the implementation of 3D scanning can be used in conjunction to augmented reality and the visualization of hands position in space through data recording in order to get a real time digital template of the design (Fig 62). By implementing this feature in the machine, designers can use other designer's creations in order to learn and replicate those designs. The purpose of this implementation is to

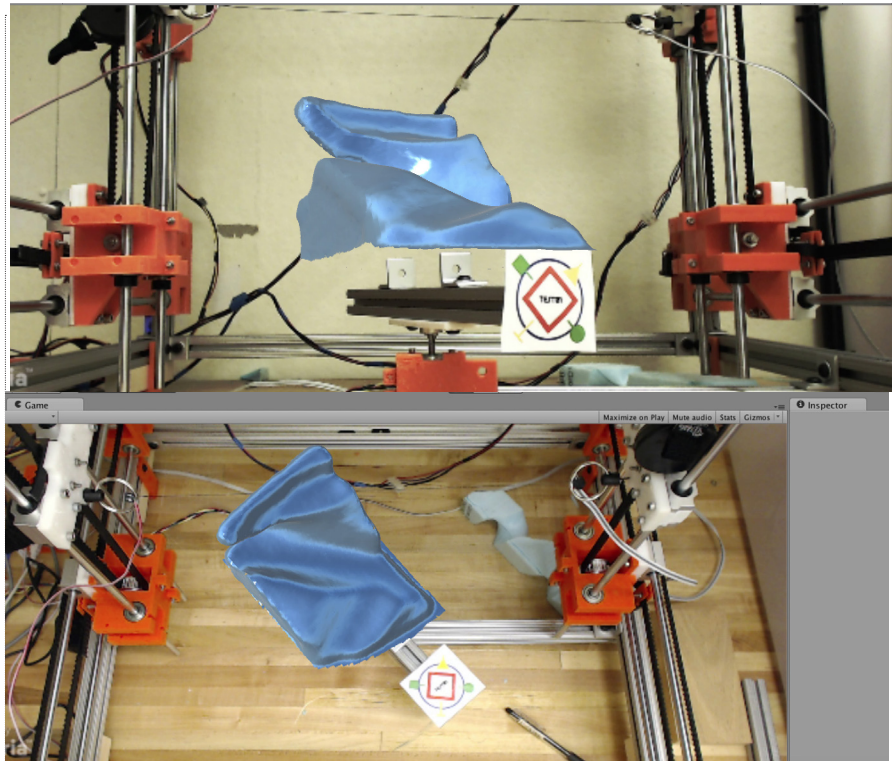


Fig 62

First tests of real time scanning and display using Kinect and augmented reality.

promote processes by which the designer learn by imitation and repetition in order to create original work (mentioned in previous chapters). A simple test of these features was executed as a proof of concept using UNITY 3D, webcams and augmented reality libraries such as ARTOOLKIT<sup>13</sup>

As a long term implementation, I have considered to expand the project by increasing the scale of the system in order to orient it to the production of architectural components in a bigger scale. The purpose of this is testing the limits of real time interaction in a more demanding scenario such as the building industry. Moreover, the development of a bigger scale machine brings new challenges to the project in terms of practical implementations, moving from foam prototyping using hotwire, to other applications such as interactive 3D printing or interactive subtractive fabrication processes. Finally , by moving to other implementations at bigger scale can be the way to prove some of the thesis assumptions in terms of concrete applications in which the use of the machine can give some extra features to humans that can not be achieve with naked hands.

13- <http://www.artoolkit.org>





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## 6 References

- Ackerman, E. "Constructing knowledge and transforming the world". [PDF] In *A learning zone of one's own: Sharing representations and flow in collaborative learning environments*. (Tokoro, M.; Steels, L. Eds.). IOS Press, Amsterdam, Berlin. Oxford, Tokyo, Washington, DC. Part 1. Chapt.2. pp. 15-37.
- Andrews, Noam."Climate of oppression" in *Log 19*, spring/summer, 2010. p137-151.
- Bazjanac, Valdimir. "The Promises and the Disappointments of Computer-aided Design." In *Reflections on Computer Aids to Design and Architecture*, ed. Nicholas Negroponte. 17-26. New York: Petrocelli/Charter, 1975.
- Clark, A. (2004). *Natural-Born Cyborgs: Minds, Technologies, and the Future of Human Intelligence* (1 edition). New York: Oxford University Press.
- Coons, Steve. "Reflections beyond SKETCHPAD" In *Reflections on Computer Aids to Design and Architecture*, ed. Nicholas Negroponte. 17-26. New York: Petrocelli/Charter, 1975.
- Dreyfus, H. (1986). *Mind Over Machine* (Reprint edition). New York: Free Press.
- Dreyfus, H. L. (1992). *What Computers Still Can't Do: A Critique of Artificial Reason* (1 edition). Cambridge, Mass: The MIT Press.
- Flusser, V. (2014). *Gestures*. (N. A. Roth, Trans.). Minneapolis: Univ Of Minnesota Press.
- Gillian, N., Knapp, R.B. and O'Modhrain, S. (2011) "An adaptive classification algorithm for semiotic musical gestures" in *Proceedings of the 8th International Conference on Sound and Music Computing*, Padova, Italy, July 2011.
- Hallam, E., & Ingold, T. (Eds.). (2008). *Creativity and Cultural Improvisation*. New York, NY: Bloomsbury Academic.
- Ihde, D. (2002). *Bodies in Technology*. U of Minnesota Press.
- Ingold, T. (2010). *Bringing Things Back to Life: Creative Entanglements in a World of Materials* (Working Paper). Realities / Morgan Centre, University of Manchester. Retrieved from <http://www.manchester.ac.uk/realities/publications/workingpapers/>
- Kolarevic, B. (Ed.). (2003). *Architecture in the digital age: design and manufacturing*. New York, NY: Spon Press.
- Lakoff, G. (1987). *Women, Fire, and Dangerous Things* (1 edition). Chicago: University Of Chicago Press.

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Latour, B. (1994). On Technical Mediation - Philosophy, Sociology, Genealogy. *Common Knowledge*, 3(2), 29–64.

Malafouris, L. (2013). *How things shape the mind: a theory of material engagement*. Cambridge, Massachusetts: MIT Press.

Maldonato, M. (2014). *The Predictive Brain: Consciousness, Decision and Embodied Action*. Brighton ; Chicago: Sussex Academic Press.

Milne, Murray. "Whatever Became Of Design Methodology?." In *Reflections on Computer Aids to Design and Architecture*, ed. Nicholas Negroponte. 17-26. New York: Petrocelli/Charter, 1975

Nakamura, Fuyubi, "Creating or performing words? Observations on Contemporary Calligraphy" in Hallam, E., & Ingold, T. (Eds.). (2008). *Creativity and Cultural Improvisation*. New York, NY: Bloomsbury Academic.

Negroponte, N. (1975b). *Soft architecture machines*. Cambridge, Mass: The MIT Press.

Negroponte, N. (Ed.). (1975). *Reflections on computer aids to design and architecture*. New York: Petrocelli/Charter.

Oxman, R. (2006). Theory and design in the first digital age. *Design Studies*, 27(3), 229–265. doi:10.1016/j.destud.2005.11.002

Radman, Z. (Ed.). (2013). *The hand, an organ of the mind: what the manual tells the mental*. Cambridge, Mass: MIT Press.

Robinson, D. (2013). *Feeling extended: sociality as extended body-becoming-mind*. Cambridge, MA: MIT Press.

Schmidt, R.A (1975) A Schema theory of discrete motor skill learning. in *Psychological Review*, vol 82. American Psychological Association.

Schön, D. A. (1987). *Educating the reflective practitioner* (1st ed.). San Francisco: Jossey-Bass.

Stiny, G. (2006). *Shape: Talking about Seeing and Doing*. Mass.

Suchman, L. (2006). *Human-Machine Reconfigurations: Plans and Situated Actions* (2 edition). Cambridge ; New York: Cambridge University Press.

Sutherland, Ivan "Structure in drawings and the hidden surface problem" In *Reflections on Computer Aids to Design and Architecture*, ed. Nicholas

Negroponte. 17-26. New York: Petrocelli/Charter, 1975.

Visser, W. (2006). *The cognitive artifacts of designing*. Mahwah, N.J: L. Erlbaum Associates.

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## 7 Figures

Fig 1. Sutherland, Ivan. Sketchpad: a man-machine graphical communication system. URL: <http://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-574.pdf>

Fig 2. ARCHMAC, in Negroponte, N. (Ed.). (1975). Reflections on computer aids to design and architecture. New York: Petrocelli/Charter.

Fig 3. Pask, Gordon, "Aspects of Machine Intelligence". in, Negroponte, N. (Ed.). (1975). Reflections on computer aids to design and architecture. New York: Petrocelli/Charter.

Fig 4. Applicon 800 system. in, Negroponte, N. (Ed.). (1975). Reflections on computer aids to design and architecture. New York: Petrocelli/Charter.

Fig 5. HUNCH using the Sylvania Tablet. Negroponte, N. (1975b). Soft architecture machines. Cambridge, Mass: The MIT Press.

Fig 6. Sketch Recognition and Interpretation by HUNCH. Negroponte, N. (1975b). Soft architecture machines. Cambridge, Mass: The MIT Press.

Fig 7. From diagram to architectural Layout. ARCHMAC. Negroponte, N. (1975b). Soft architecture machines. Cambridge, Mass: The MIT Press.

Fig 8. Achim Menges, Reseach Pavillion 2012, URL: <http://www.achimmenges.net/?p=5561>

Fig 9a. Matsys Lamp: <http://matsysdesign.com/2009/>.

Fig 9b. Parametric architectural techniques in clothing URL: <http://dreamsinmonochrome.tumblr.com/post/103497446946>.

Fig 9c. Parametric 3d printed shoes URL <http://continuumfashion.com/shoes.php>.

Fig 9d. Al-Bahr Towers Facade URL:[http://ad009cdnb.archdaily.net/wp-content/uploads/2014/05/5384b0c2c07a8044af0000c0\\_light-matters-mashrabiya-translating-tradition-into-dynamic-facades\\_al\\_bahr\\_towers\\_tower\\_-christian\\_richters.jpg](http://ad009cdnb.archdaily.net/wp-content/uploads/2014/05/5384b0c2c07a8044af0000c0_light-matters-mashrabiya-translating-tradition-into-dynamic-facades_al_bahr_towers_tower_-christian_richters.jpg).

Fig 9e. ITKE Aarboskin pavilion URL: <http://inhabitat.com/itke-constructs-new-arboskin-pavilion-with-388-recyclable-bioplastic-pyramids/rh2239-0028-2/>

Fig 10. Linear Operation. Image by the author

Fig 11. Circular Interaction. Image by the author

Fig 12. Glass Lab MIT. Image by the author.

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Fig 13. Glass Lab MIT. Image by the author.

Fig 14. Constructing Numerical Control Workshop, Diego Pinochet and Victor Leung 2015.

Fig 15. 2 Axis CNC machine with paintbrush. Early Image by the author

Fig 16a. step 1 - manual tracing. Image by the author

Fig 16b. step 2 - Using Computer vision, detect blobs.

Fig 16c. step 3 - Extract boundaries.

Fig 17a. Grasshopper definition Image by the author

Fig 17b. G Code. Image by the author

Fig 17c. Machine motion. Image by the author

Fig 18a. Example of auxiliary movements: Dipping and shaping the brush  
Image by the author

Fig 18a. Tracing Movements. Image by the author

Fig 19. Tests. Image by the author

Fig 20. Adjusting the brush. Image by the author

Fig 21. Interacting with a tablet device. Image by author

Fig 22. Making Gestures implementation diagram. Image by the author

Fig 23. Hidai Nankoku, Japanese calligrapher performing. in Nakamura, Fuyubi, "Creating or performing words? Observations on contemporary Japanese Calligraphy." in Hallam, E., & Ingold, T. (Eds.). (2008). *Creativity and Cultural Improvisation*. New York, NY: Bloomsbury Academic.

Fig 24. Heater Hansen, "Emptied Gestures" in <http://www.heatherhansen.net/emptied-gestures/z7k8hfrmiyg27m0xpb7d0300s9dchf>.

Fig 25. Stelarc, "The third Hand". Gibson, W. (2007). *Stelarc: The Monograph*. (M. Smith, Ed.). Cambridge, Mass.: The MIT Press.

Fig 26. How gestures work according to Schmidt's schema theory. Image by the author.

Fig 27. Machine interaction proposal diagram. Image by the author.

Fig 28. Implementation of interaction types. Image by the author.

Fig 29. Gestural Interaction diagram. Image by the author.

Fig 30. Gesturing. Image by the author.

Fig 31. Interacting with the machine. Image by the author.

Fig 32. Drawing output. Image by the author.

Fig 33. Tangible interaction diagram. Image by the author.

Fig 34. Tangible Interaction. Image by the author.

Fig 35. Grabbing gesture recognition. Image by the author.

Fig 36. Drawing output. Image by the author.

Fig 37. Collaborative interaction diagram. Image by the author.

Fig 38. The machine solves the maze finding the optimal path to find the target. Image by the author.

Fig 39. The user through the use of gestures, modifies the environment or select a new target. The machine solves in real time the new optimal path to the target. Image by the author.

Fig 40. The motion of the path is translated as GCode to the machine. Image by the author

Fig 41. Interactive design and fabrication system. Image by the author.

Fig 42. Making gestures setup . Image by the author

Fig 43. Hardware and software components. Image by the author.

Fig 44. Diagram of the machine functioning author. Image by the author.

Fig 45a. Using the machine by performing gestures in a more natural way than just hand tracking in a limited space. Image by the author.

Fig 45b. Gesture performance. Image by the author

Fig 45c. Real time skeleton model according to user ID. Image by the author.

Fig 45d. Joints detection and features extraction. Image by the author.

Fig 46. Data flow between hardware and software. Image by the author.

Fig 47. Code fragments of basic functioning of GRT through OSC.Data recording + training

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Fig 48. Training phase: on screen visualization of user gestures tracked. Image by the author.

Fig 49. The machine and prototype. Image by the author.

Fig 50. Rotational movement in relation to body action. Image by the author.

Fig 51. Performing a gesture to rotate the 5th axis to the right. Image by the author.

Fig 52. Free exploration and machine adjustment. Image by the author.

Fig 53. First outcome from the adjustment phase. Image by the author.

Fig 54. Machine and prototype detail. Image by the author.

Fig 55. Start motion. Image by the author.

Fig 56. Hold position. Image by the author.

Fig 57. Free movement Gesture. Image by the author.

Fig 58. Making image sequence. Image by the author.

Fig 59a. Single curvature shape.

Fig 59b. Double curvature shape.

Fig 59c. Free exploration shape.

Fig 60a. Making a cube shape 1.

Fig 60b. Making a cube shape 2.

Fig 61. Diagram of data collected by Making gestures project. Image by the author.

Fig 62. First test of real time scanning and display using Kinect and augmented reality. Image by the author.

Fig 64. Interactive Fabrication group CMU. <http://www.interactivefabrication.com>.

Fig 65. Studio Greyshed. URL: [www.gshed.com](http://www.gshed.com)

Fig 66. The Free-D. [http://web.media.mit.edu/~amitz/Research/Entries/2013/9/10\\_THE\\_CASTLE.html](http://web.media.mit.edu/~amitz/Research/Entries/2013/9/10_THE_CASTLE.html)

Fig 67. The interactive robotics group. <https://interactive.mit.edu>

## Appendix A

### Precedents

During the development of this thesis I researched -beyond historical precedents such as HUNCH or SKETCHPAD- other projects related to Human Machine Interaction or Human Computer Interaction related to design , fabrication or construction. Moreover, finding similar projects in the field of interactive fabrication allowed me to frame and confirm the motivations of developing Making Gestures as a unique project.

In the interactive fabrication field, projects developed by the computation group at Carnegie Mellon University<sup>14</sup>, are good examples of applications in design and fabrication through which the development of interfaces in mobile phones, tablets or projections, designers can control machines in a more fluid way to produce physical outputs. Projects developed by the Interactive Fabrication Group<sup>15</sup> at CMU are one of the first implementations by which designers using tangible interfaces were able to control not only software but fabrications machines with the goal of bridging design and digital fabrication taking real time input from the user.

In addition , projects developed by studio Greyned<sup>16</sup>, are examples of complex technical implementations in order to expand digital fabrication and robotic construction taking advantage of new technologies such as augmented reality and the use of sensors. Finally, the FREED project developed by Amit Zoran<sup>17</sup> at MIT Medialab, was considered in the initial precedent study because of its characteristics of a real time performing tool with the capacity of having a direct use of computational methods to make prototypes in real time in the same way analog tools are used.

In the field of interactive robotics, one special case studied is the one of the interactive robotics group directed by professor Julie Sha<sup>18</sup> at MIT. The projects developed inside the group, take into consideration the development of interactive application using robotics , artificial intelligence and machine learning algorithms in order to establish a real time collaboration with the machine. The projects take into account the realtime interaction in order to complement the strengths of human and machines in order to perform and accomplish what neither can do separately. The use of intelligence models in order to generate collaborative workflow to industrial applications was an inspiration model to understand the advantages of implementing the idea of collaboration in this thesis.

Acknowledging the existence of previous work in the field of interactive fabrication, this thesis starts from the base that Making gestures is different in many ways to the projects currently developed. I argue this because most of these projects are goal oriented or achieve interaction only by directly controlling machines and digital tools through tangible interfaces. Because of this, they neglect the addition of collaborative models in which the machine behavior is also a crucial factor in the interaction. In the case of the freeD, the project is goal oriented since it starts from a predefined model loaded in the tool to make a physical prototype. Moreover, if the process is always different because is based on performance of the designer to make the prototype, the fact that is always goal oriented limits the possibilities of moving in a more fluid way

14- <http://code.arc.cmu.edu/about/>

15- <http://www.interactivefabrication.com>

16- <http://www.gshed.com/>

17- <http://web.media.mit.edu/~amitz/Research/Research.html>

18- <https://interactive.mit.edu/about/people/julie>



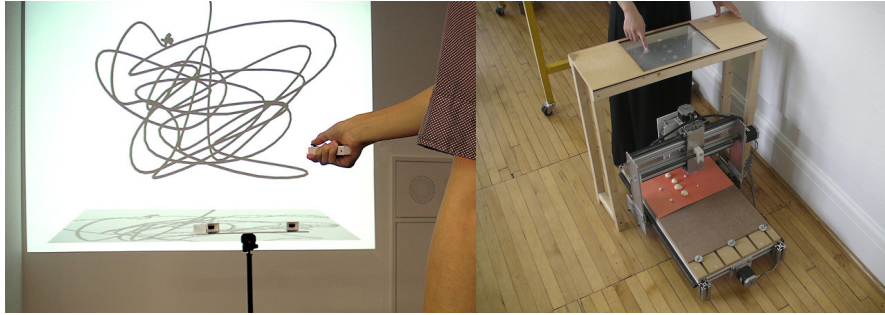


Fig 63  
Interactive Fabrication  
group CMU

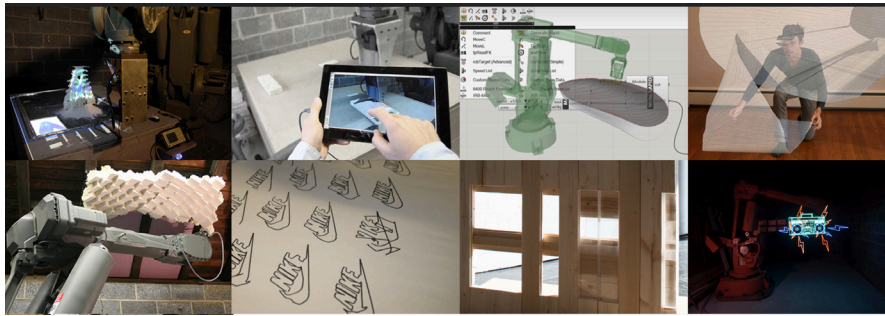


Fig 64  
Studio Greyshed



Fig 65  
The Free-D



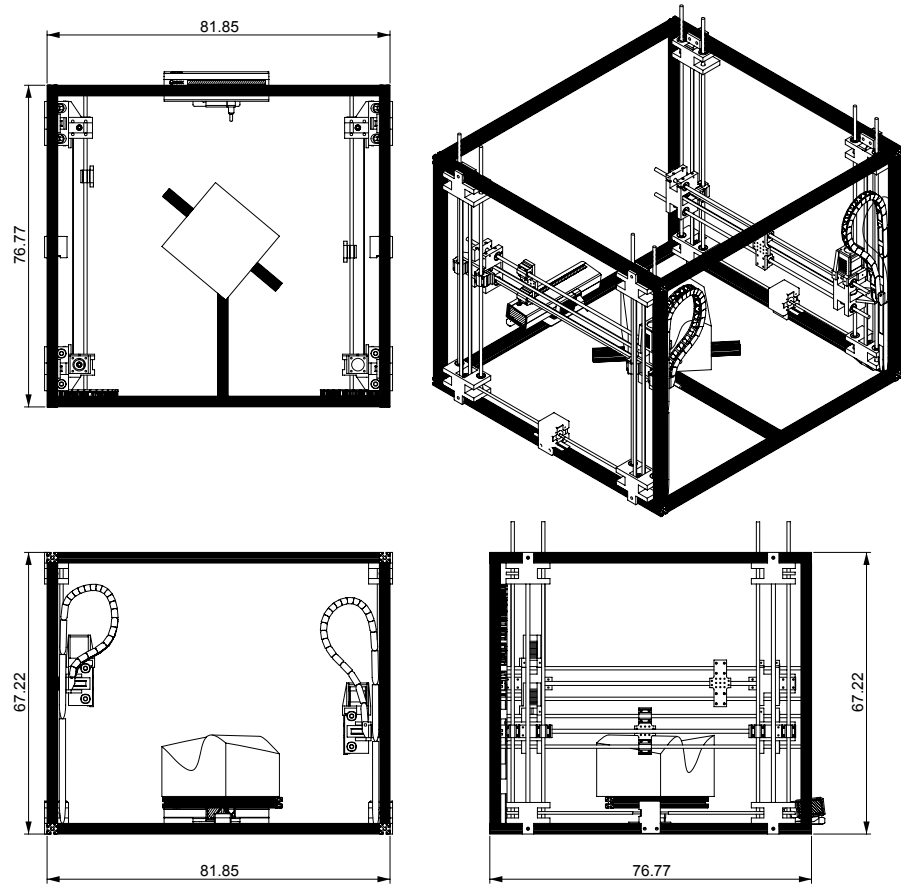
Fig 66  
Interactive robotics  
group MIT

to 'something else'.

In the case of the projects developed by studio Greyshed and the Interactive fabrication group at CMU, they don't take into account the fact that the operation of a computer or digital fabrication machine comprises different tasks and procedures which are proper to the machine and need to be added as part of the interaction in a more fluid way. Finally because of many of the answers to interaction with machines are outside of the design field and are more related the integration between computer science and robotics, I was able to formulate the Making Gestures project as a process that not only take into consideration the designer's characteristics of the human performing but also the peculiarities of machine making in order to achieve a real collaboration.

## Appendix B

### Project files and code



The large amount of files that were produced during the development of the project and writing of the thesis, all the information was uploaded to a GITHUB account. Moreover, because of the development of the machine and the software was intended as an open source initiative, the intention of making the information publicly available -i.e. 3D models, code, and building diagrams- I encourage readers to modify and extend the use of this system for their own purposes.

The documentation is available under MIT license at the following URL.

[https://github.com/dipinoch/making\\_gestures](https://github.com/dipinoch/making_gestures)

