Antithetical Colloquy

From operation to interaction in digital fabrication.

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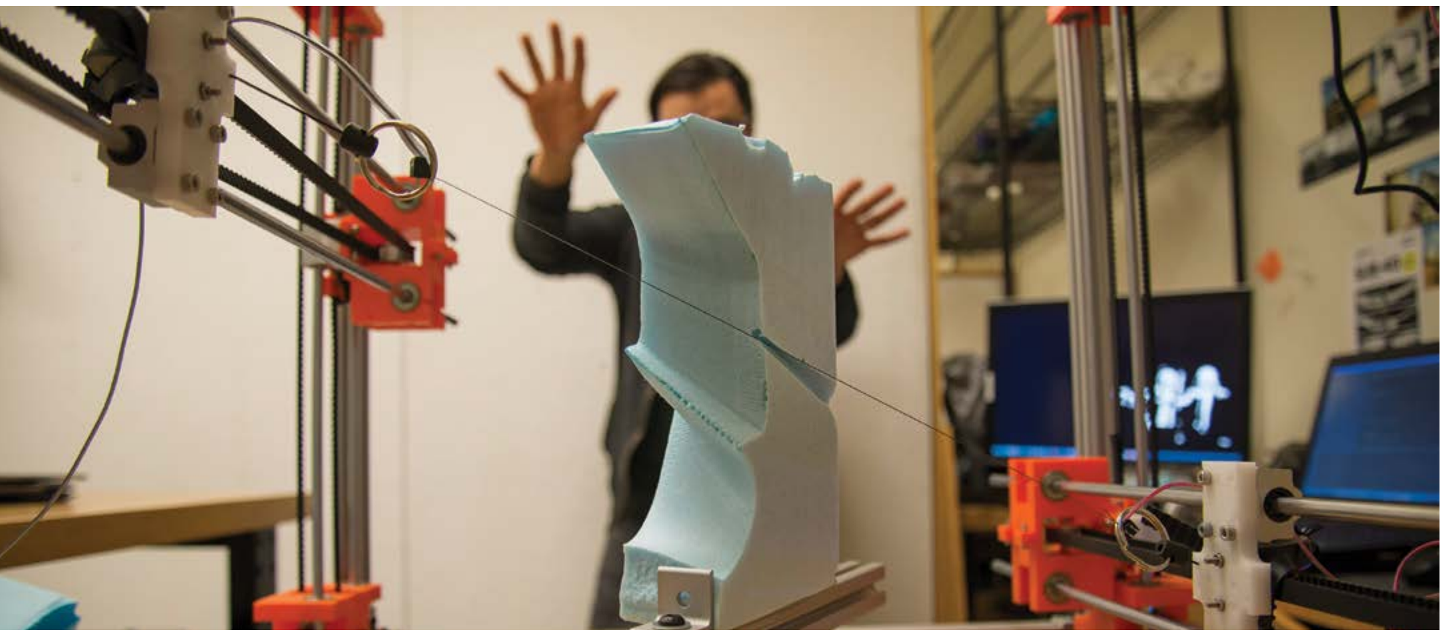

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ABSTRACT

This paper, introduces a cybernetic approach to digital design and fabrication by embracing aspects of embodied interaction, behavior and communication between designers and machines. To do so, it proposes the use of body gestures, digital/tangible interfaces and Artificial Intelligence to create a more reciprocal way of making.

The goal is to present a model of designing and making as a 'conversation' instead a mere dialog from creator to executor of a predefined plan to represent an idea. In other words, this paper proposes a platform for interaction between two antithetical worlds—one binary/deterministic and the other perceptual/ambiguous—by focusing in the exploratory aspects of design and embracing aspects of improvisation, ambiguity, imprecision and discovery in the development of an idea.

1 'Making Gestures: An interactive personal fabrication system'. Diego Pinochet 2013–2015'.

INTRODUCTION

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 learns about design problems. Nonetheless, certain criticism has emerged about the use of digital tools in terms of the cognitive and creative aspects of the process of creating original work. The use of digital fabrication tools currently relies upon a model of 'tool operation' in which designers typically pause the ideation or 'creative' part of the process to produce a physical representation of an idea. Furthermore, in separating designing and prototyping from the development of that idea in a digital environment with a mouse or keyboard, and then 3d printing, laser cutting or CNC milling, the act of making and learning through exploration disappear. A designer cannot touch, feel or interact directly with the objects he or she creates; this insightful moment of sensing, feeling and discovering new things is lost.

This paper identifies three fundamental problems of digital design and fabrication processes, establishing a theoretical discussion about the use of digital tools in architecture at the early stages of the design process. Moreover, this paper inquires after possible implementations to engage architects in more perceptual digital design processes through the use of interactive fabrication machines. This paper shows the development of different interaction experiments with fabrication machines by the use of machine learning techniques to train and interact in a more personalized way with machines. In this paper, a model of interaction is proposed that seeks to transcend the 'hylomorphic' model (the imposition of form over matter) imperative in today's architectural design practice to a more reciprocal form of computational making. To do so, this paper seeks to reconcile design and making by exploring real-time interaction between mind, body, and digital fabrication tools. Furthermore, by using body gestures and imbuing fabrication machines with behavior, the goal is to establish an interaction model that embraces ambiguity and the unexpected, engaging the designer into more improvisational and insightful design processes. This presents a new perspective about digital fabrication where error and imprecision are incorporated into the unfolding process of making something to discover new things.

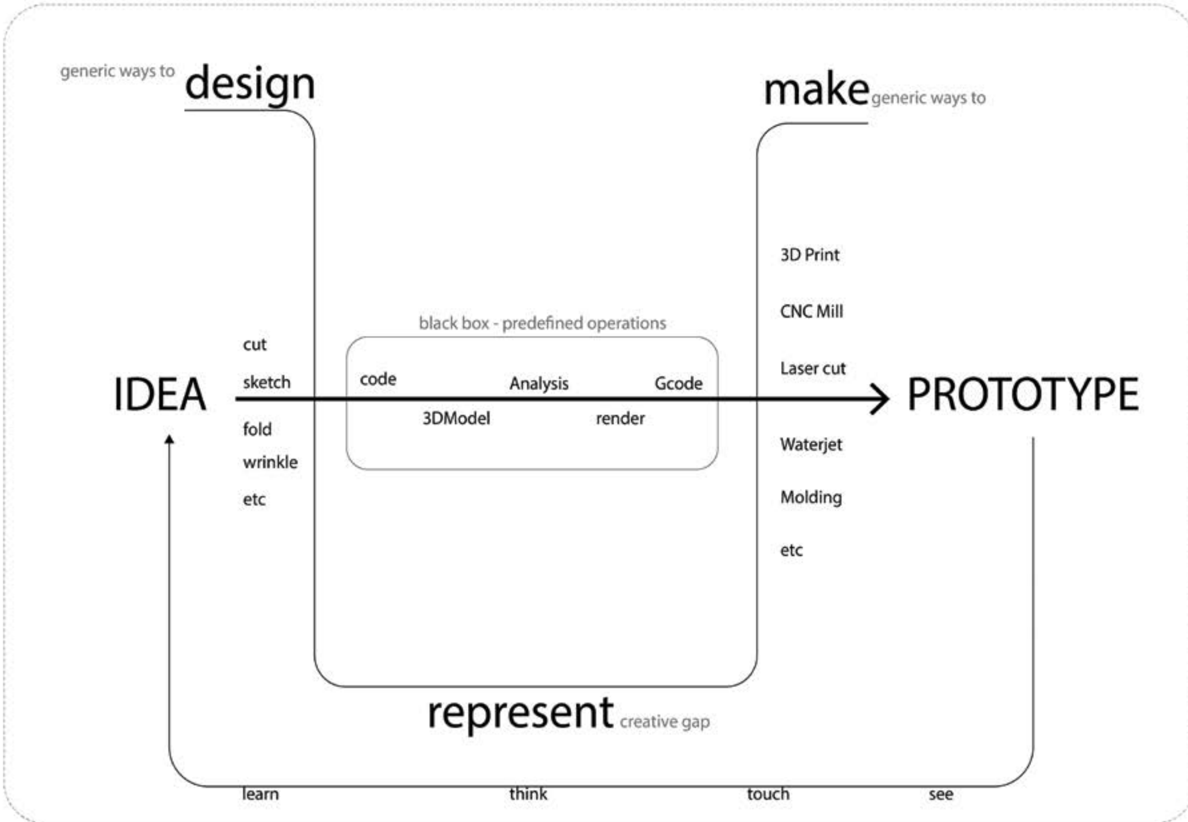
DIGITAL DESIGN AND MAKING, THREE PROBLEMS

By using digital tools, focusing on the representation 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 the digital in design. 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 the design process. From this black-box concept, it is possible to identify the other two problems. The first is the use of generic operations—embedded into software and hardware—to impress a specific non-generic design idea. The final one, is the 'creative gap' that occurs as a result of using black-boxed generic operations in the transition from design idea to the fabrication of a prototype.

The 'Black-Box' Problem

Since the beginning of CAD during the 1960's, 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, the current use of digital tools somehow maintains this assumption by leaving 'the human' out of important and crucial moments of design, such as 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 structures to the architect. In the case of digital fabrication techniques, the assumption that the digital is somehow a complete or sufficient representation of the real has ignored the phenomenological dimension of meaning (Perez-Gómez, 2002, p13), that involves aspects of materiality or human intervention as an active decision making actor. In the process of making through digital machines, the process follows a linearity of events from the generation emergence to the physical prototype.

This cause-effect relation between the idea and prototype, relies on the evaluation of results in order to modify the structure that originated that output. The translation from idea, to digital models, to G-code, to material, involves a series of translations and black boxed operations that happen without human intervention. Furthermore, these operations are dependent upon formal or codified knowledge about 'ways of representing' that don't take into account the perceptual and phenomenological contingency and interaction of the agents involved. This black boxed world, or what Perez-Gómez (2002, p13.) defines as "the between dimensions" (from idea to prototype), is a problem not present in analogue processes since they don't rely on predefined structures of codified knowledge. Conversely, these processes are based on a constant unfolding/evolving processes of tacit knowledge as situated action.



2 Design-make dichotomy.

Design 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 process of making, exploring and having feedback through seeing and doing is lost. Perceptual aspects of ideating and making something through a continuous unfolding of tools, material behavior and perceptual aspects of design, sometimes considered as 'tacit knowledge', 'personal knowledge' or even 'embedding,' are neglected.

Hence, why should designers accept that the physical manifestation of our ideas should be processed and expressed through this black-box using generic operations and constrained by predefined structures embedded in a software? Plotting a drawing, 3D printing or CNC milling 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 the body and its senses (primarily vision and touch), tools (pen, knives, scissors) and matter (clay, paper, ink, wood) according to a constant evolving logic, perception and tacit knowledge about what happens at the moment of acting. If we consider cooking as an analogy, we can understand the difference between linear deterministic processes of making, such as 3D printing, and reciprocal perceptual processes such as drawing, painting or crafting. Cooking involves a predefined generic structure in the form of a recipe that indicates rules, procedures, and also quantities to be followed. Nonetheless, the act of cooking involves the perception and action of the chef by being aware of certain 'moments' impossible to quantify or code beforehand. Thickness, smell, taste, consistency, color, and so on are parameters often described with ambiguous sensorial instructions that are either visual—'bring to a boil' , 'until turns red' , 'until water is absorbed' – or physical – 'al dente', 'until it reaches hard consistency.'

The 'Creative Gap'.

To Dreyfus (1986), it is clear that computers are indispensable for some tasks due to some characteristics where they surpass human's capabilities such as precision or exhaustion. He asserts that computers are specifically useful in CAD applications due to their capacity to compute large amounts of information, improving efficiency by optimizing, drafting, analyzing and representing (p.xii).

Nonetheless, what happens if in the process of making a prototype the designer 'sees something else´ and needs 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 or even cooking—affect aspects of creativity and cognition of the design process? Furthermore, how can we reformulate the digital fabrication process in order to design and fabricate 'on the go' without worrying about elaborating deterministic and fixed structures? How can we enter the "space between dimensions" (Perez-Gomez, 2002, p.23) in order to enable a 'conversation' with fabrication tools to learn from error, imprecisions, see new things, be creative and find new meanings about what we do, on the making, not only before or after.

The design and fabrication practice through digital technology is constrained by a constant imposition of predetermined ideas over matter (Hylomorphism) by "a violent assault on a material prepared 'ad-hoc' to be informed with Stereotypes" (Flusser, 1991, p.43). Today's digital fabrication works by relying on a model that imposes a linearity of events 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 perception and action present in analog processes.

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- happen in order to generate more insightful and creative design processes?

TOOLS FOR REPRESENTATION VS. TOOLS FOR CREATIVITY

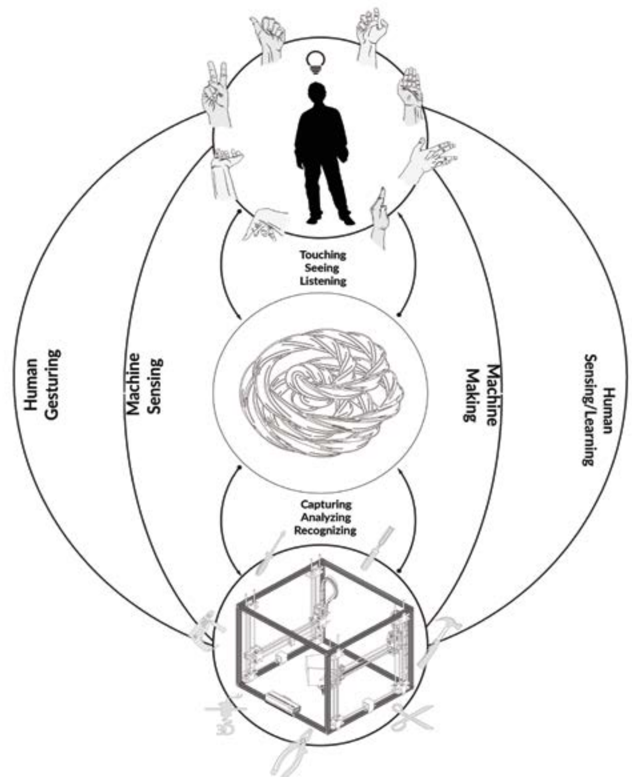
According to Schön (1987), design is a form of artistry and making, where learning about a specific topic or design emerges through actions (conscious and unconscious) and exploration (p. 29). The designer learns to design by knowing and "reflecting in action," reinterpreting and re-elaborating actions in the particular moment where the act of design takes place, producing new meanings and coherence. This suggests that every creative process is accompanied with a material representation as a by-product of a constant interaction with our surrounding objects. By interacting with our surrounding objects, we learn and produce meaning and therefore reason. As Robinson (2013) argues, 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 inside a parametric model as a set of topological relations. In contrast, if design is considered 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 relate to the use of digital tools (CAD-CAM) as task performing machines instead of activity performing machines. In other words, we program machines to perform several tasks, however we don't interact with them to perform an activity. The little interaction between creator and executor (designer and machine) is constrained to an insufficient interface (clicking and typing) to grasp the main qualities of both as a fluid interaction (Figure 3)

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). Robinson (2013) identifies this interaction (mind/tool) as 'Circulation,' in which tools become externalized mind, and cognition is internalized tools (p.35). This circulation is crucial to comprehend the role of digital fabrication tools in the creative part of design to discover the affinities and dissensions established by using tools as 'objects to sense' and 'objects to think' with. The mind-tool interface, is not static 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"(Robinson, 2013, p.60). Thus, senses and action as gestures play a crucial role in this negotiation.

From Operation To Interaction

To Idhe (2003, p.91), the relationship between humans and technology is explained through "intentionality" and what he calls "middle ground" or "area of interaction/performance". Idhe asserts that the only way to define the relationship between humans and non-humans is through actional situations that happen in a specific time and place. This relates to real time interaction in which not only humans but also objects -which Idhe and Latour refer as the "non humans"- are redefined as a "Sociotechnical" Assemblage (Latour, 1994, p.64) that transforms both agents into



3 Interactive fabrication diagram. Design + Make on the go.

something else. 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 mechanical 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.

Furthermore, 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. The difference between 'opaque' and 'transparent' technologies relies on the degrees of transparency according on how well technologies fit our individual characteristics as humans (Clark, 2004, 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 of its use. Suffice it to say that the current model of digital fabrication is based in pure tool operation, neglecting real time interaction with tools, leaving important parts of cognitive processes of making aside. The many intricacies of digital tools—the black-box—lead the designer to pause creation and focus in the elaboration of plans for representation—the creative gap—that in many cases lead one to rely in software decisions—the generic—relegating the design act to an initial effort which is later rationalized by a fixed structure.

Therefore, the main problem this paper addresses is the linear 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.'

CREATOR/EXECUTOR INTERACTION: THREE EXPERIMENTS

In order to implement real time interaction between humans and machines, this paper explores the role of human gestures and the capability of a machine to discriminate, recognize, "understand" and act according to a specific gesture. To do so, three experiments are implemented: 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 (Figure 4).

The basic Machine setup, consisting of a 2-axis CNC machine controlled by GRBL, an open source firmware for Arduino capable of controlling up to 3 stepper motors using one UNO board. Python and C# were used to communicate hardware, software and the designer.

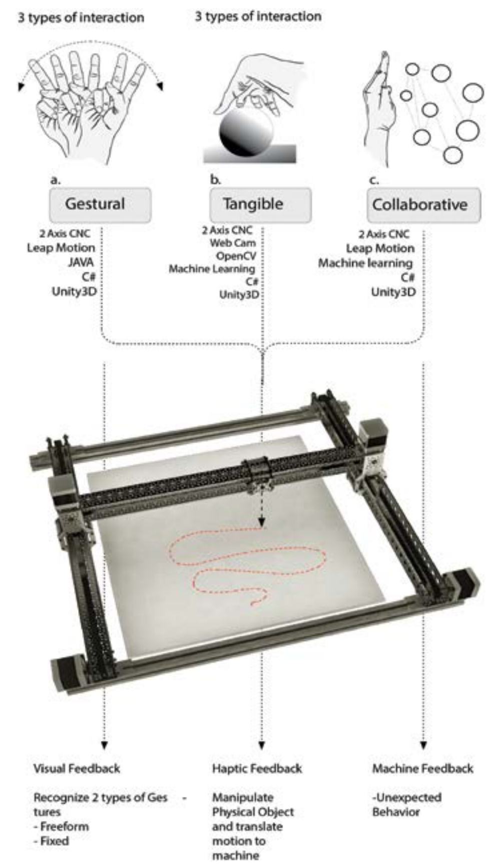
Gestural Interaction

Gestural Interaction (Figure 5), was implemented to test the use of Motion tracking sensors 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 on the other hand the auxiliary movements as fixed operations to help the process of drawing.

To track gesture motion and get the data to perform gesture recognition, a LEAP motion sensor was used. This sensor, through the use of 2 infrared cameras is capable to track hands in space with high accuracy, with the position of hands represented by a 3D skeleton model. The data from the 3D skeleton model was used to perform gesture recognition using Gesture

Recognition Toolkit (GRT), 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 (ANBC), it was possible to perform gesture recognition using the LEAP motion sensor. Initially developed to recognize musical gestures, the ANBC proved to be very useful to distinguish other type of gestures 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 others), and most of all, its capacity to be quickly trained using a 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, hands' positions in space were used to perform free exploratory movements in XY dimensions controlling a pen. The data from the classified gestures were associated to specific auxiliary fixed operations such as drawing different geometrical shapes, or to start or stop motion from the machine. 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 the generation of a workflow where the two types of movements (free and fixed) were successfully recognized and performed.



4 Human – machine interaction diagram.

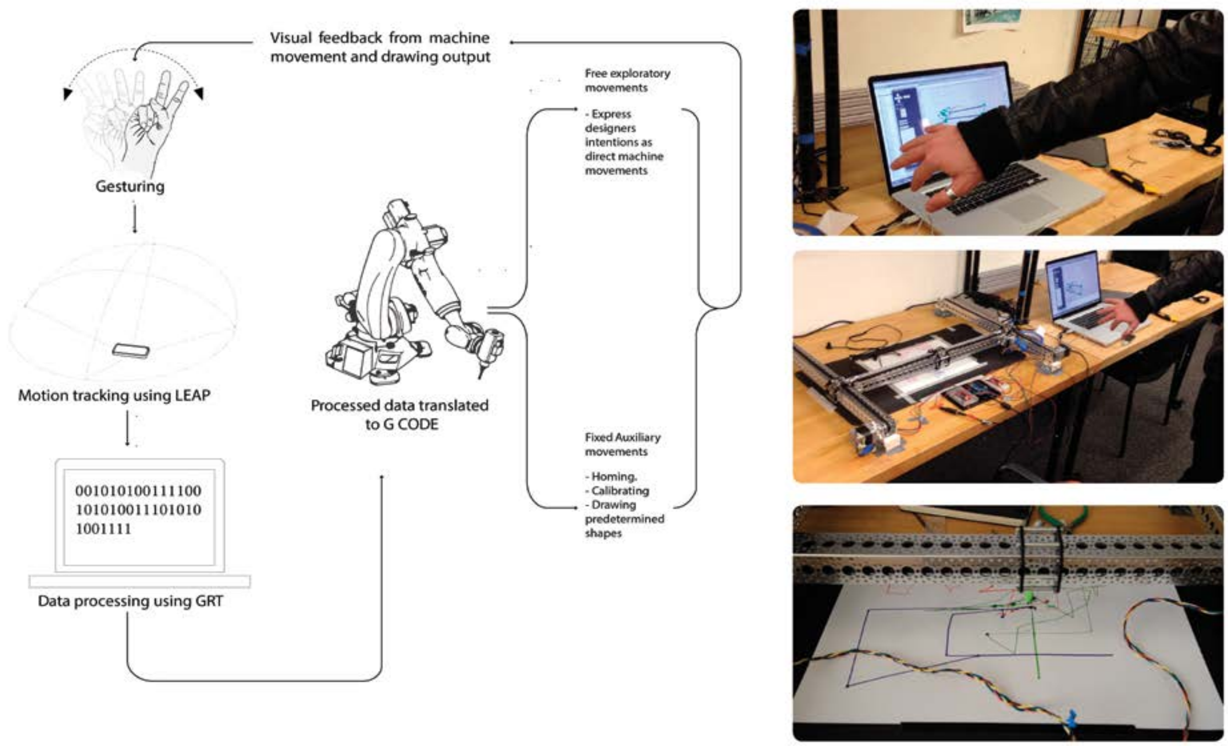
Tangible Interaction

The implementation of Tangible interaction (Figure 6) sought the development of a system to manipulate physical objects in space to interact with the machine. Through object recognition, by blob, edge, and color detection, it was possible to track objects' positions to control the CNC machine. By using computer vision algorithms, it was possible to recognize different objects extracting their positional data to recognize free and auxiliary movements.

This facilitated an indirect type of interaction, considering haptic as an important part of the interaction process. The user could have a different experience than gestural interaction by touching objects and producing machine movement. Combining the techniques developed from gestural interaction, using both a webcam and the Leap, it was possible to perform free movements of the objects in space in addition to the recognition of fixed gestures such as 'grabbing' an object to enable the motion of the machine while the object is manipulated.

Collaborative Interaction

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 of a dialog where the machine could produce unexpected output and behavior according to what the designer proposes by modifying a virtual environment using gesture recognition to get user input and Artificial intelligence as machine behavior (Figure 7). 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 it by promoting the emergence of unexpected behavior from the machine to solve a problem. Furthermore, two different AI algorithms were implemented. First, Depth First Search (DFS) was used to create a random environment as a maze. Second, optimal search algorithm (A*) was used to find a solution to the proposed environment as the machine behavior. In this case, the human suggested a target inside the maze, and the machine tries to find the optimal path (using A*) to reach that target. The path calculated to the target is then translated to G Code. The software interface allows the user to specify in real-time a new target and/or modify the maze shape by moving objects in the virtual and physical environment. According to this, the machine can recalculate on the fly the new trajectory to the new target. In this case, it is the user who



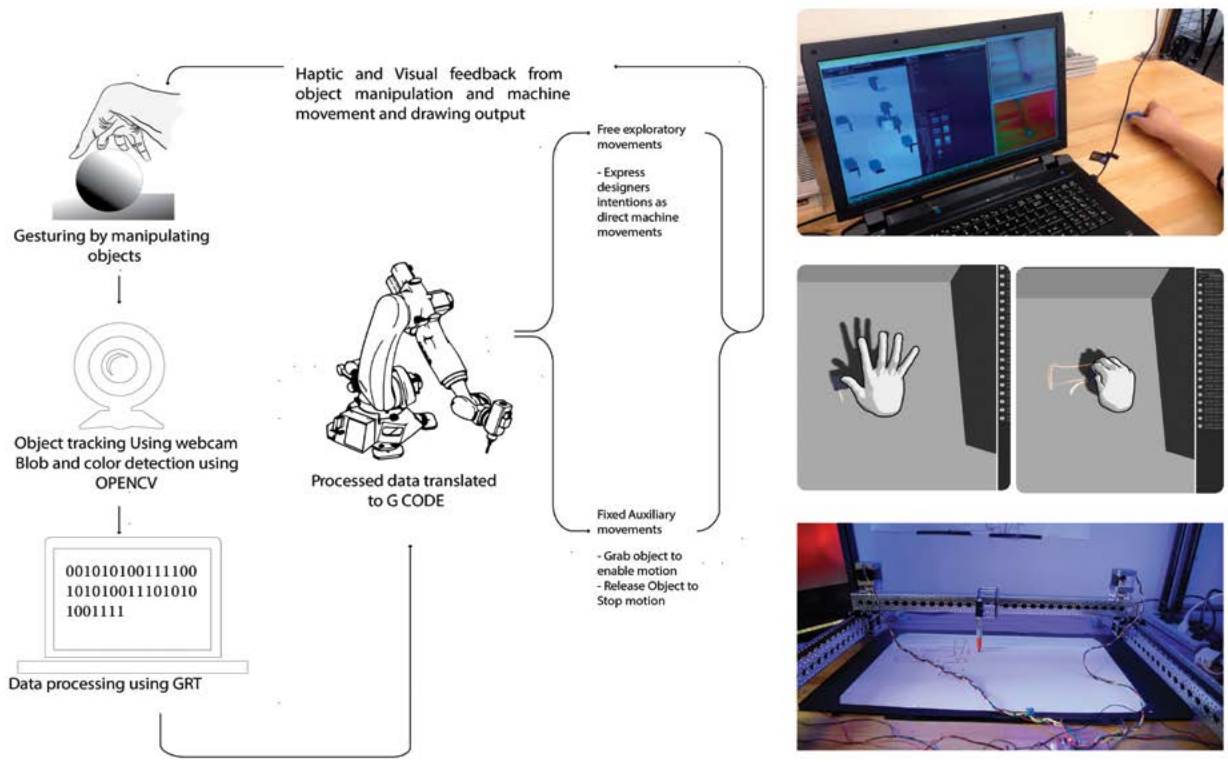
5 Gestural Interaction diagram.

generates indirect input so that the machine, through a constant recalculation of the maze solution from its current position to the target, generates motion expressed as drawings and unexpected behavior to designers.

CONCLUSIONS

By focusing on gestures, we can formulate mechanisms in which humans can communicate with machines establishing a fluid interaction with digital tools, capturing the moment where creativity and original work emerges. Moreover, this paper argues that creativity and originality don´t rely on pre-conceived ideas or elaboration of plans, but on the relationship of perception and action as creativity and knowledge promoters, in which the concept of real time interaction between humans, through gestures and machines, and through AI, is the key to use digital fabrication in more creative ways. At this point, one can assert that by the development of gestural machines, we can solve the three problems identified in the previous chapters—the black box, the creative gap and the generic. Moreover, in order to promote the improvisational aspects of design as exploration, we need not only machines emulating designer's movements but interactive machines that by the use of sensors and actuators can enhance our experience, establishing a constant circulation of action and perception from both sides. Nonetheless by stating this, it's not the intention of this paper to seek the development of 'Intelligent cognitive design machines'. The proposal is that we can take advantage of current developments on robotics, artificial intelligence, CAD/CAM to grasp in a computational way the very aspects that make design an original enterprise.

The different types of interaction were successfully implemented in terms of the fluid response from the machine according to designer's gestures. The basic implementation of machine learning algorithms to discriminate fluid exploratory gestures from symbolic type of gestures (preprogrammed) served as the base to understand how the interaction with the development of a more sophisticated machine should take place. Furthermore, it was clear that simple act of translating hand motions into XYZ coordinates in the machine was insufficient in order to take advantage of its characteristics. Moreover, to achieve a seamless interaction between machine and designer, the interplay between the fixed gestures—associated to a machine´s pre-coded operations—and the free movements is crucial. The development of the three types of experiments as separate models for interaction worked as the basis for a robust software improvement at bigger and more complex scales by integrating different technologies in a circular loop of capturing, analyzing and expressing the analyzed human gestures as improvisation and consequently machine action(Figure 8)



6 Tangible Interaction diagram.

By using fabrication machines imbued with behavior, performing in real time according to designer's improvisation, the problem of black-boxing can be solved. Moreover, by making tools capable of becoming internalized, designers can concentrate on design and making in a similar way analog tools are used. This paper showed experiments that did not focus on the manipulation of intermediate artifacts translating an intention into material, but rather on a process that participates seamlessly in a dance of agencies between designer, tools and materials. As a consequence, the problem of the 'creative gap' could be avoided. 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 multiple translations present in digital fabrication processes so the designer focuses in creating by seeing and doing-making 'on the go'.

Finally, it proposes a solution to the problem of generic outcomes, allowing the impression of the self onto our material world, capturing designers' gestures and translating them as intentions in real time to materials. This process starts from the argument that the originality and the creativity emerge from the fact that no gesture is the same as any other, because of the ever-changing properties and characteristics of the participants (material, visual, psychological) of the interaction.

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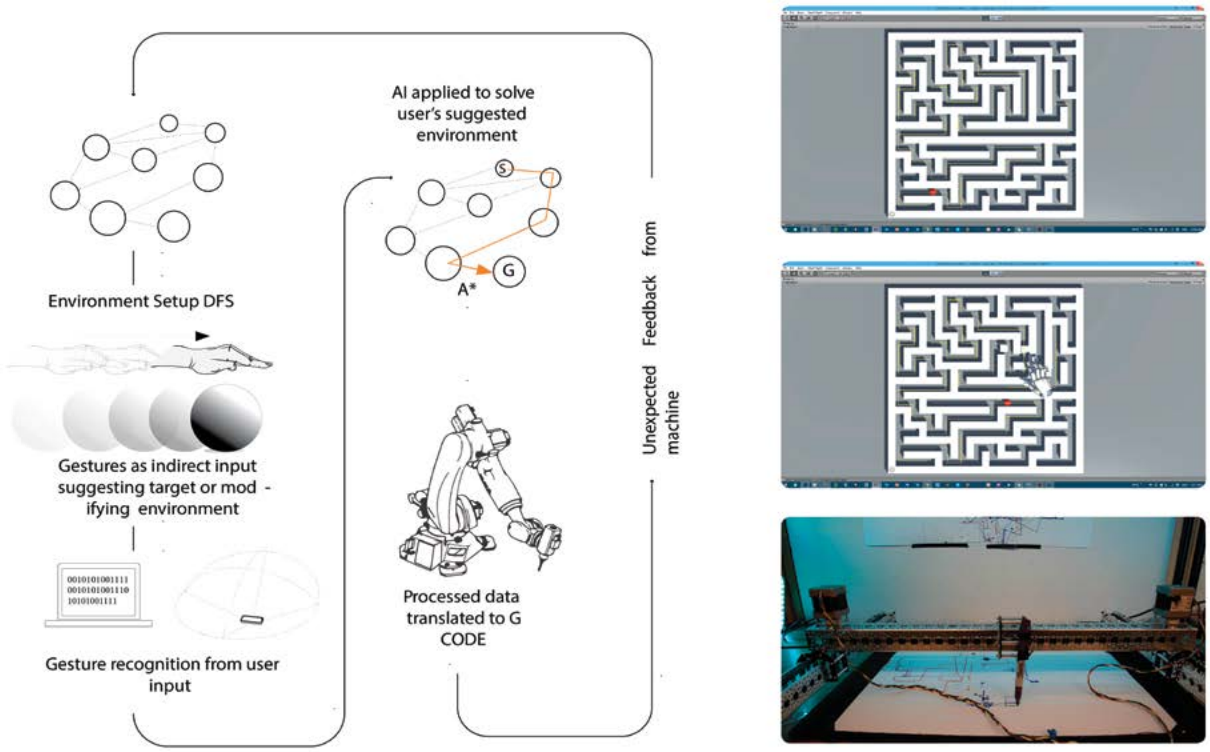

7 Collaborative Interaction diagram.

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IMAGE CREDITS

Figures 1, 3–4, 6, 8: Pinochet, 2015

Figures 2, 5, 7: Pinochet, 2014

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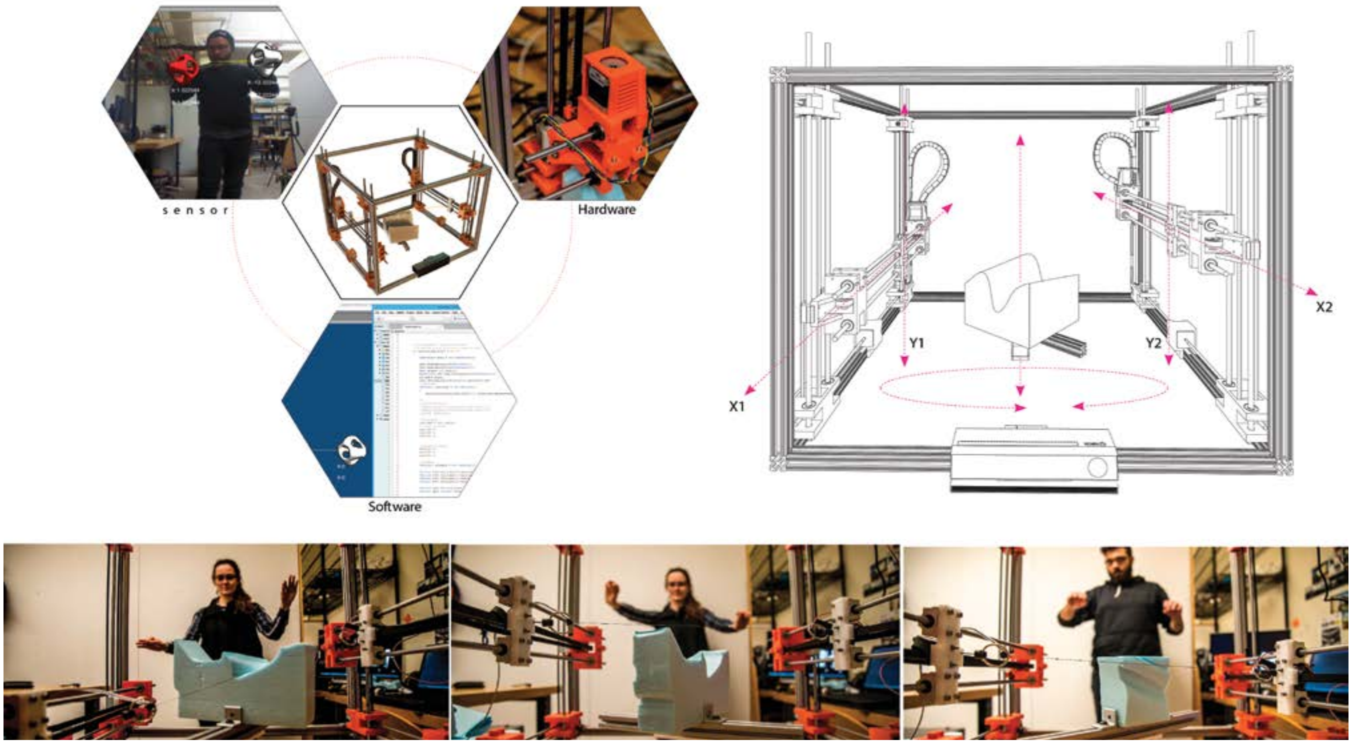

8 Making Gestures project implementation.