Imperfection in Fabrication: Seeking Authenticity Through Dissolvent Forming

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Abstract

This paper introduces a methodology called 'Dissolvent Forming' and its implementation in the context of digital fabrication. Dissolvent Forming Methodology (DSM) is an experimental surface finishing work in which polystyrene material is shaped with a chemical reaction unlike the traditional physical subtraction methods. DSM covers three components: programming code, tools and actions. Processing environment is used to generate a graphical user interface for controlling the variables. The tool component includes design of a chemical end-effector that can be used with industrial robotic arms. Moreover, DSM covers three layers: Conceptual framework, simulation model and fabrication model. In the scope this paper, a small scale prototype of end-effector which is compatible with Arduino Braccio robotic arm was developed and tested. The action component consists of 2D drawing; the translation of the drawing into robotic arm through programming environment; subtraction of polystyrene material by using end-effector and chemicals through robotic arm.

This study can be considered as an attempt to create an experimental design and fabrication flow to provide uniqueness in mass customization through programming and simulating the material (polystyrene) behaviour. In the proposed and examined workflow, the actions of drawing, design and material forming were executed concurrently. In the scope of the paper, a series selected surface finishing outcomes were examined in user tests and the findings derived from the user test were presented.

1. Introduction

The advances in digital design and fabrication technologies have been transforming the relationship between designers and design models. The way designers engage with the notion of 'form' has been diversified and has become more complex. In the conceptual ground, there has been a shift from form to formation, geometry to the relations resulting with geometry, typology to topology[1], object to field[2]. Beyond the conventional physical models or three dimensional representation in computer environment, various models such as performative, generative, evolutionary[3], parametric, mathematical, meta models have become a part of understanding, manipulating and developing design models. Today, the integration of different tools, methods and approaches became more crucial to coordinate and handle complexity of the digital production processes. On the other hand, new skillsets are required to grasp the "disjointed, complex and often voxellated" [4] nature of design data.

In Aish's words, "Tools require complementary skills to be effectively used". Aish et al. [5] underlines the necessity of cognitive skills to expand the affordances of the tools. Cognitive skills have potential to become complementary for exploring new potentialities of form, geometry, material and computation. In this sense, getting familiar with the basics of computer programming, logical operations, data types, loops and conditional expressions might be helpful for designers to gain a better understanding of how digital design and fabrication tools might perform. However, there is a delicate line between being a passive user of existing tools and actively participating in the design, development and future of tools. At this point, there is a risk to be trapped in the given frame of digital interfaces and not generating out of the box ideas. As a result, either the linear logic of the computer programming or strict workflow operations of digital tools might dominate the design alternatives through decreasing the diversity. Similar algorithms, operations and assumptions might lead similar outcomes to some extent. Moreover, widespread sharing of open source code, samples, tutorials may result with morphological similarities in designs made through digital means. Therefore, a crisis of authenticity occurs. Picon [6] conceptualizes one of the dimensions of this tension as transition from authorship to ownership . Another dimension of the authenticity crisis is concerned with whether the design environment allows to make mistakes and encounter emergent situations. These concerns in mind, this study focuses on the new and creative use of conventional digital fabrication tools, as well as the search for authenticity that carries the imprint of the designer on repeatable and iterative production cycles..

Regarding the authenticity problem in numerical manufacturing processes, we argue that the concepts of 'imperfection', 'error', 'human subjectivity', 'information loss during translation' have potential to provide opportunity to allow exploration of emergent possibilities in design process. Zoran [7] indicates the field of creativity embedded between the computational control over digital design and fabrication processes and imperfection in his article titled "A Manifest for Digital Imperfection" [7] underlying also the problem of style, identity and authorship in digital design and fabrication processes. Moreover, Krapp[8] highlights the insightful potentialities of error culture, the concepts of noise and glitch in a broader perspective for all productions in/through digital media.

This study aims to investigate the concept of authenticity in mass customization through accentuating situations of imperfection in digital fabrication processes. The motivation of the study was derived from whether it might be possible to explore new methods which can be considered as combination of craft, mass production and craftsmanship in digital age. In other words, when using digital fabrication tools, how can we differentiate the final product specifically to the designer, even if the work, algorithm and design flow is the same? In a broader sense, this study can be considered as an attempt to seek improvisational values in the context of hand and material encounter in digital fabrication.

2. Authenticity in Numerical Manufacturing

"Abstract and concrete have, for instance, become seamlessly linked one to another. Uniqueness and variation can now be reconciled" [6]

Digital design and fabrication technologies led to the re-emergence of originality and diversification debates in design. Since the 1990s, with the exponentially growing use of parametric design approaches, it has become possible to control the digital design model directly from the initial assumptions to the final production. In the context of numerical manufacturing technology, the search for authenticity has different foundations, including but not limited to material (matter), tool, operations, parameters and flow of the algorithms. The reflection of digital transformation in architecture was outlined by Corser as:

"Starting in the mid-1990s, however, three powerful forces began to emerge that are starting to transform significant aspects of both design practice and project delivery: intelligent, feature-based parametric modelling; building information modelling (BIM); and mass-customization" [9].

Remarkable number of pioneering applications in this area have been reflected in architecture practice and smaller scale boutique experiments as well. Relatedly, the search for the 'non-standard' has become more apparent in repetitive and automated processes. For example in the facade of Eberswalde Technical School Library which was designed by Herzog & de Meuron in 1997; materiality and pictorial character, representation and abstraction, repetition and differentiation come together [10]. The differentiation in Eberswalde Technical School Library sample was achieved through the changes in texture, color, pattern and topologies [10]. Beyond ornamentation, Acoustic Barrier project located in Utrecht Leidsche Rijn in the Netherlands designed by ONL (Oosterhuis and Lenard) can be considered as one of the pioneering works which brought new understandings to the CNC based manufacturing techniques [11]. The design information was decoded through parameters, logical operations and relations and the structure of the Acusting Barrier was generated by scripts. In that sense, it can be considered as an early sample of 'informed design' technique, rule based customization or in other words information driven design process [11]. In addition to these, as a notable example for CNC-milled foam finishing, Ruy Klein's Klex1 project [10], and as demonstrating digital craftsman values in the surface finishings De Young Museum which built in 2005 [10, 12] can be listed.

Apart from reflections of the digital fabrication on architectural practices, search for aesthetic on the interdisciplinary platform are progressing in various focuses and drivers such as material, workflow/algorithm and interaction [13-17]. The common denominator of the out-of-the box digital fabrication studies concerning authenticity is that the design process itself is designed in a holistic manner. There has been a need for integrating different technologies, medium, data, actions and operations in relation with the requirements of each design process. Therefore, the action of translating the design information from one medium to another, from one type of representation to another accelerates the possibility of encountering emergent results and also loss of information to a certain extent. In the context of numerical manufacturing, the tension between automation and craft values, precision and imprecision, geometric model and the fabricated, creates a buffer zone for designers to explore affordances of the material and tools intuitively.

Suggesting an embodied and continuous experience of making in everyday life in which physical and digital environments are fused, Devedorf unfolds the discourse of “being the machine”[13]. Devedorf’s hybrid fabrication system proposal can be considered as a search for qualities between human and machine modes of producing [13]. FreeD, hand-held digital milling tool, is a computer aided finishing approach which leds a shift from a precise and fully informed digital manufacturing process to the human subjectivity [16, 17]. Similar to FreeD, DSM has contributions to the design of the workflow, tool and mechanism. On the other hand, different than FreeD, the actions, design decisions and manipulations made in DSM are recorded in a history panel which provides recursive jumps in the action history. Considering the subjective contribution of the user in computer aided manufacturing process, Computer Aided Painting (CAP) is another work which combines user’s contribution and effector properties to get similar results in digital medium [18]. The design of an end effector and the spraying event mechanism of CAP and DSM have similarities, while the workflow as a whole and the algorithms used are different. MetaMorphe [15] consisting of direct manipulation, scripting interface, generative module layers focuses on utilizing the existing repository of 3D models. Direct manipulation allows user to make partial changes in the scale of the 3D digital model. Scripting interface of MetaMorphe, allow users to manipulate the design model through programming. Generative module and genetic algorithms provide opportunity to differentiate models [15]. Different than MetaMorphe, the workflow of DSM, the actions of drawing, design and material forming were executed concurrently. Moreover, John’s experiments involving wax vaporizing and melting operations allow immediate changes in the physical state of material [14]. Therefore the enhancement of the affordances of the material leads unpredictable and emergent outcomes. In Johns’ words: *“Rather than developing design in a linear progression from idea to computer-simulated model to fabrication tool and material result, the process allows these elements to operate concurrently or in rapid and recursive succession” [14].* In addition to those, as an intuitive and feedback-driven formation processes, ‘Procedural Landscapes’ by Gramazio-Kohler research group involves the tension between the computer generated model and the final outcomes [19].

3. Experimentation

Dissolvent Forming Methodology (DFM) is derived from of a series of iterative and reflective experiments that focus on the subjective qualities in producing surface finishing by using digital fabrication tools. Five experiments were executed in total to inform the conceptual framework. In addition to this, simulation and fabrication models have been developed (Figure.1). A small scale prototype of end-effector which is compatible with Arduino Braccio robotic arm was developed and tested.

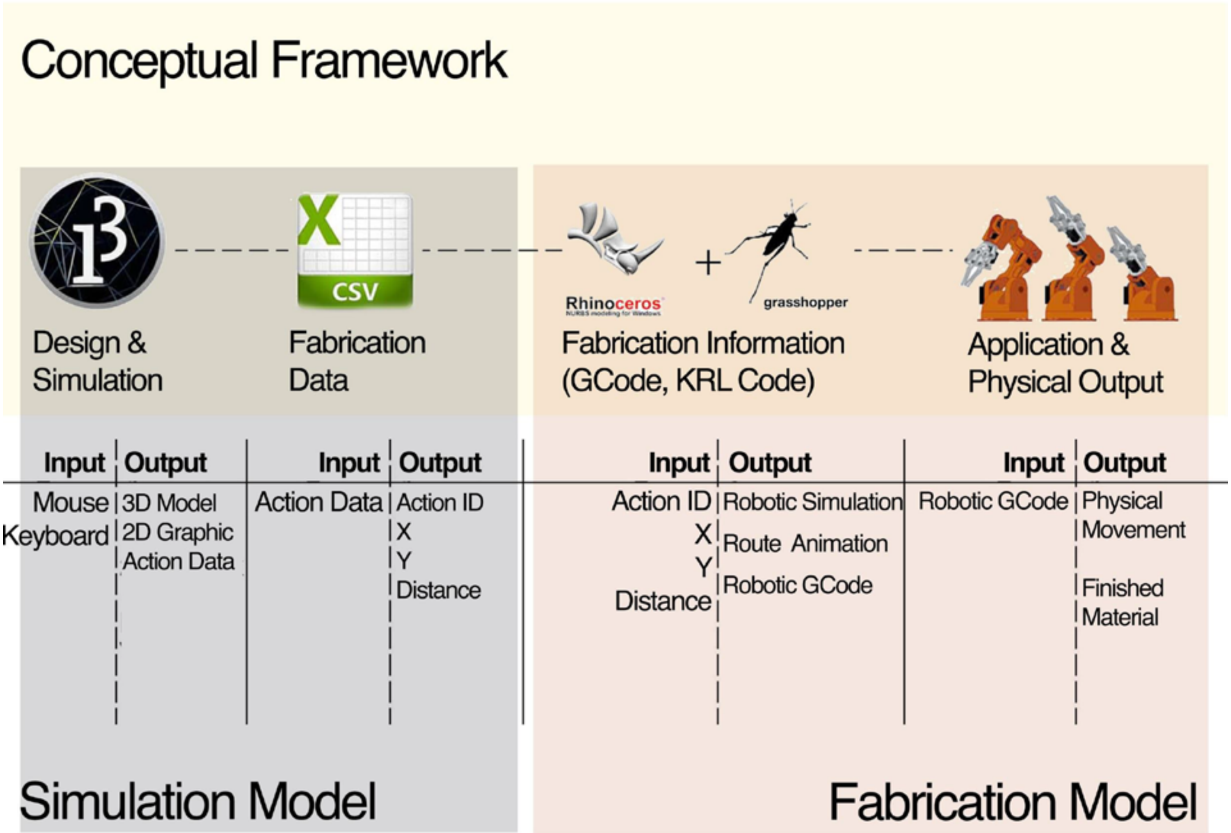


Figure.1 - Framework Diagram

3.1 Experiment Setup and Implementation

The exposure of polystyrene material to acetone in different forms is visually investigated. The initial experiments were made with the help of a container by means of pouring the foam into the foam (Figure.2). The resulting foam, which was extracted from these experiments, was intensively pierced by liquid.The materials used on the further experiments, chosen based on general information and the first experiment The second experiment in *Figure.2* shows the effect of acetone solution (constant) on a specific EPS material (constant). The amount of solution used with syringe (variable) is multiplied by the number on the columns (1ml for the 1st column, 5ml for the 5th column). The rows named “a” “b” “c” are repeated processes for comparison purpose. Similar visual effects were achieved with equal fluid and equal touch area each time. Conclusion of this experiment was; with a single variable, the effects of same amount of acetone used on the EPS material are similar in a threshold by empirical observation. Both depth and spread is increasing when the amount of applied solution increases.

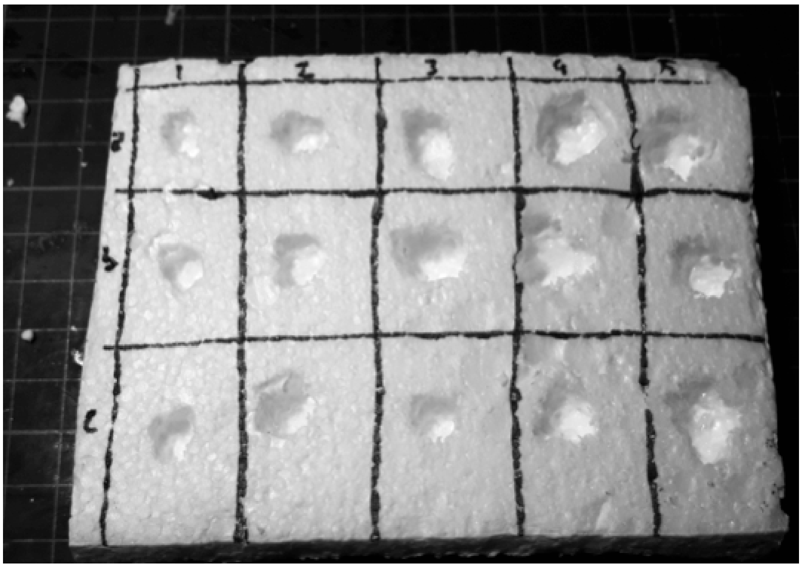


Figure.2
Identical process used in each row (a, b, c) supplies visual comparison. Each column (1, 2, 3, 4, 5) represents repeatedly increased use of solvent amount.

In the third experiment; it is tried to compare different expose methods (variable) with same amount of acetone solution (Figure.3). It is aimed to keep the amount of solvent constant but to reduce the size of the droplet as in syringe experiments. To achieve this, a 9cc-capacity airbrush and a regulated air compressor are used. It was sprayed with acetone paint gun. As a result, it was seen that the sprayed acetone did not affect the foam.

Since the solvent was in an extremely volatile physical state, it became clear that it lost its ability to dissolve in air without spraying. It was understood that the particle size formed after spraying was important.

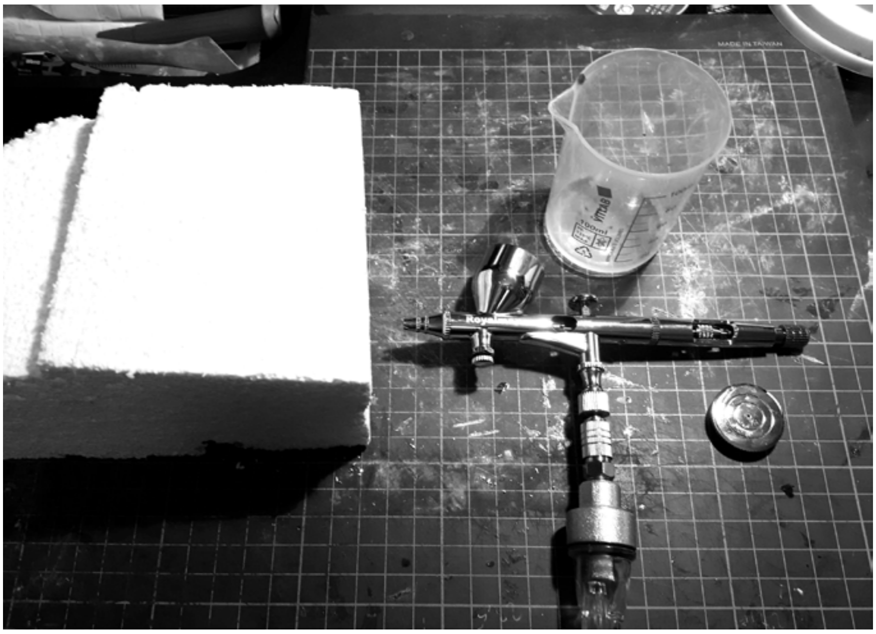


Figure.3
Airbrush setup used in the third experiment

In the fourth experiment, it is tried to eliminate the problems of the third experiment. To increase the spray particle size, spray paint nozzle is used (*Figure.4)*. The solution again pressured with the syringe mechanism to remove the air particles. The tool provided a successful spray and was considered a tool prototype for the next stage.

Figure.4
A syringe modified with a spray cap to achieve smooth spreaded exposure

In the fifth experiment, a better developed tool prototype is built (Figure.5). In this stage not only the problems are eliminated but also tool itself evolved to a end effector. A progression mechanism and a flexible arm has been added to the prototype. To provide a digital control over spraying action; progression mechanism derived power from a BYJ48 stepper motor with ULN2003a driver. Internal library (*Stepper.h*) of the ULN2003a driver is used in Arduino to create precise actions with digital inputs.

Outputs and insights derived from the experiments to refine the Conceptual Framework are listed below:

System Properties as constants and variables

Functional relationships between constants and variables;

a. *Applying variable pressure causes complex results*
b. *Pressure used on syringe changes both amount of solution used in unit time (ml/sec) and particle structure*
c. *Unstable exposure distance changes results dramatically. To reduce complexity spraying distance should kept steady in a single stroke of spray.*

Measurements of the effects based on multiple trials. Further to these inferences, the end effector was tested by using working tool prototype.

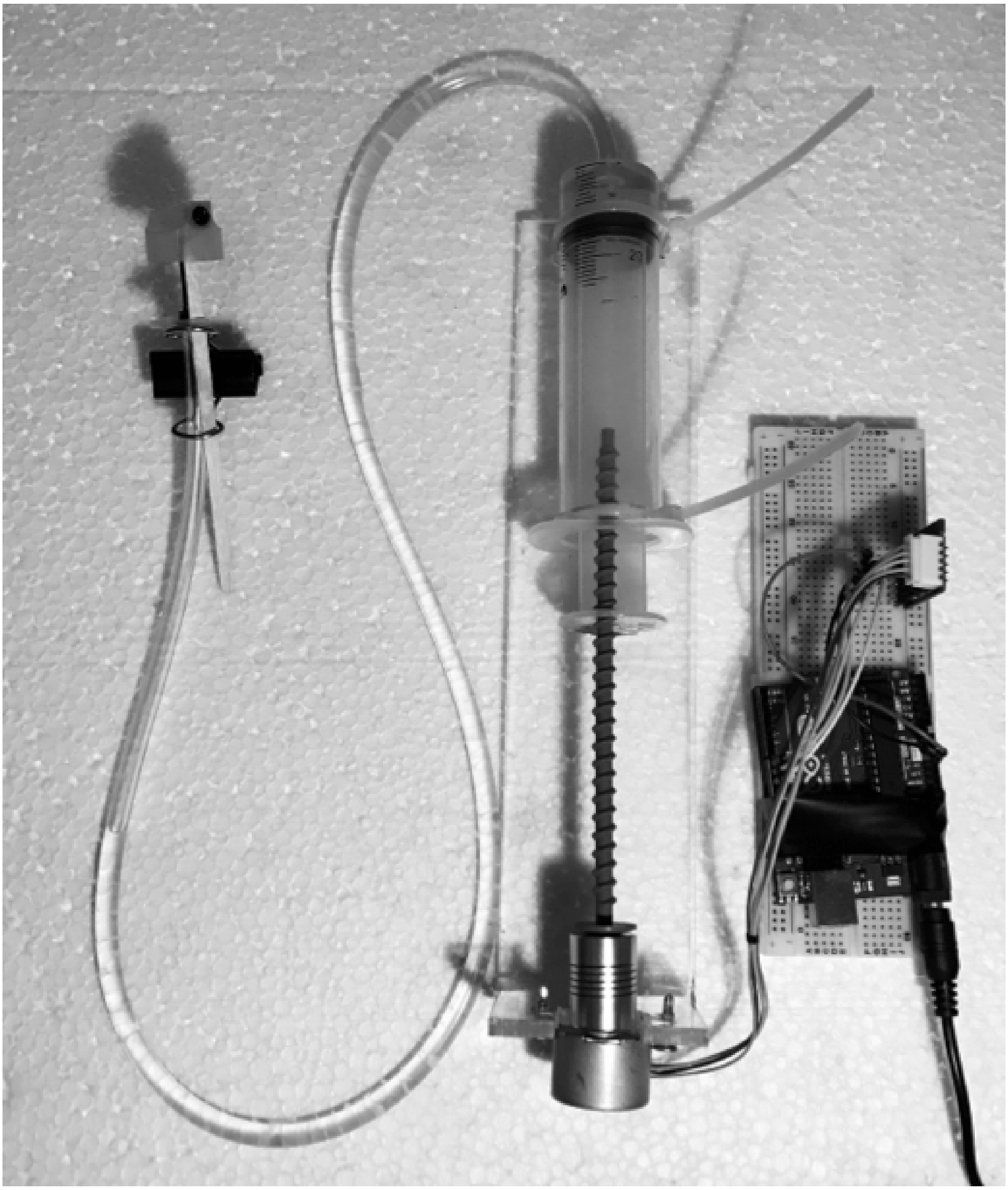


Figure.5 Modified syringe with digital controller and flexible transforming spray nozzle

3.2 Simulation Model

Constraints and variables defined in conceptual model, formed the [SYSTEM PROPERTIES] in the Simulation model. Desired model, shaped around the [SYSTEM PROPERTIES], with the ingredients; an interface that is used to design [SIMULATION], a viewer where 3D aspects of the design in progress can be seen [MONITOR] and the data recording, required for fabrication [RECORD FILE] (*Figure.6).*

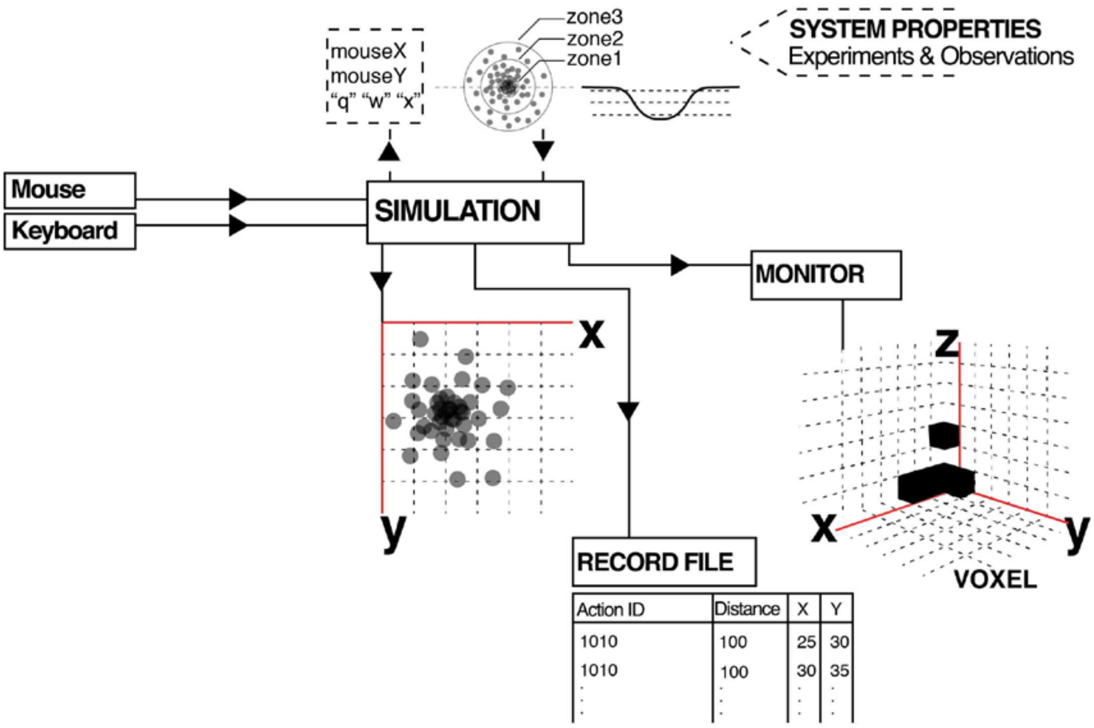


Figure.6 Simulation Model Outline with the [SYSTEM PROPERTIES], [SIMULATION], [MONITOR] and [RECORD FILE]

[SYSTEM PROPERTIES] (*Figure.7a, Figure.7b, Figure.7c)*

a. Constants
    1. Polystrene Material (30kg/m^3 EPS Block)
    2. Acetone Solution (%90 pureness)
    3. Spray Nozzle ("MTN - Montana" brand "Soft Cap" model, https://www.youtube.com/watch?v=AvPURr_aeS8)
    4. Spray Pressure
    5. Amount of spray (3ml per second)
b. Variables
    1. Spray-Material Distance
    2. Spray Movement (also defines spraying time)

[SIMULATION] was designed at the center of the whole application. Simulation part of the application basically converts mouse and keyboard inputs into stains in black-and-white range in the two-dimensional plane. This event is programmed through the direction of the data obtained from the observations. With the "Q" and "W" keys, the spray size, ie the distance of the nozzle in the factory, can be changed.

[MONITOR] simultaneously shows the voxel based 3D model of the design.

[RECORD FILE] is being created in the background of the application. When the design is finished, the "X" key is pressed and all the operations are converted to the fabrication data as a single file.

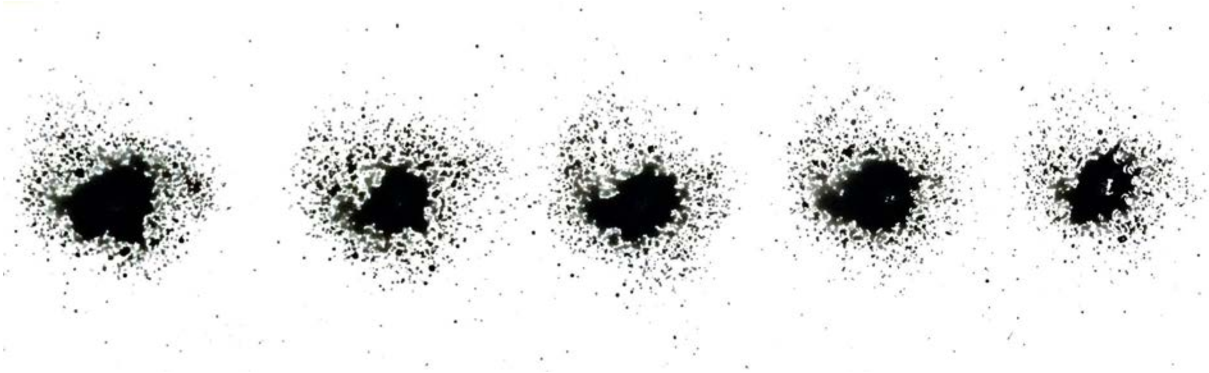
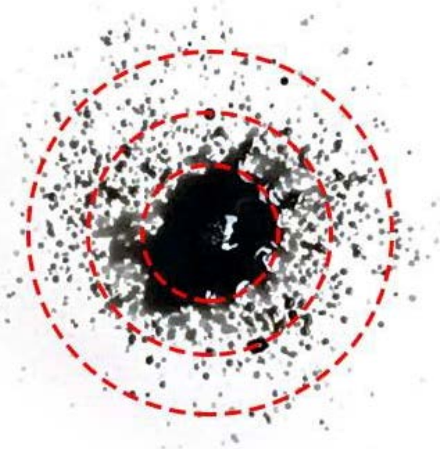


Figure.7a - Spray nozzle tests, with same amount of solution (3ml/sec), constant pressure



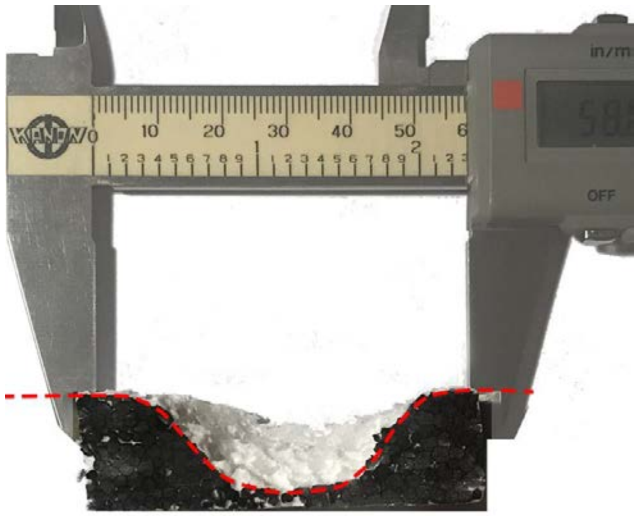


Figure.7b Density zones used in simulation   *Figure.7c Sectional effect on Polystrene*

3.3 Fabrication Model

The application created in the simulation model consists of 2 screens; design interface and
Monitor *(Figure.8)*. The design interface window works as a painting medium. Simulates the spray stains when mouse is clicked and dragged. At the same time three dimensional effect can be seen from desired camera views in the right wind

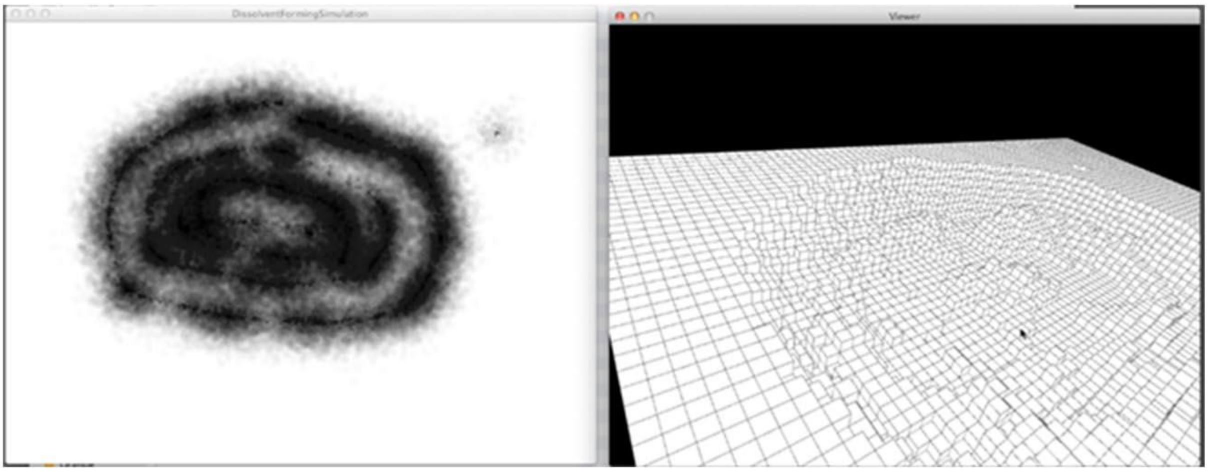


Figure.8 - Design interface (left), monitor(right)

When design process is finished, action record happened in the background can be written on a file. Sequential operations saved as a ‘Comma Separeted Value’ CSV file. File contains; [ActionID], [Spread Size], [X Axis], [Y Axis] values in an order. This file is separated into meaningful components using the Rhinoceros / Grasshopper plugin. Separated components are transformed into sequential coordinates for robot and run commands for the end effector *(Figure.9)*.

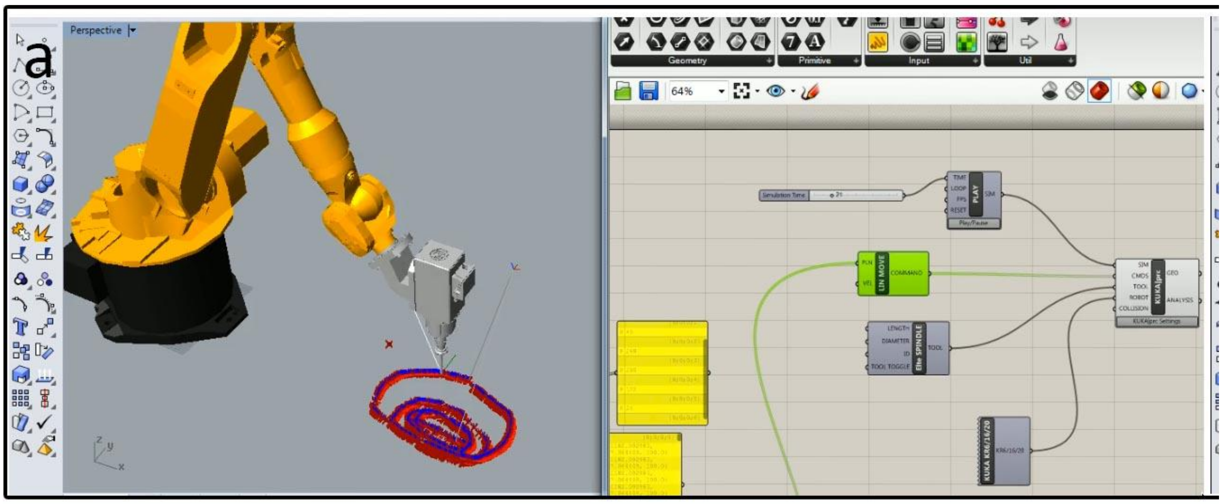


Figure.9 - KUKA robot showing the path (left). CSV values are used (right)

In the Rhinoceros, the KUKA PRC plug-in in the Grasshopper plug-in provides the KRL output of KUKA robots and robot simulation. The KRL output contains the corresponding angles in the robot joints of the instantaneous points forming the specified route. Within the scope of this project, processes up to this part have been applied but the end effector has not been used with the robot since it can not provide necessary security by the date of this paper. To finalize the project end effector is used manually with positioning helpers (*Figure.10)*.

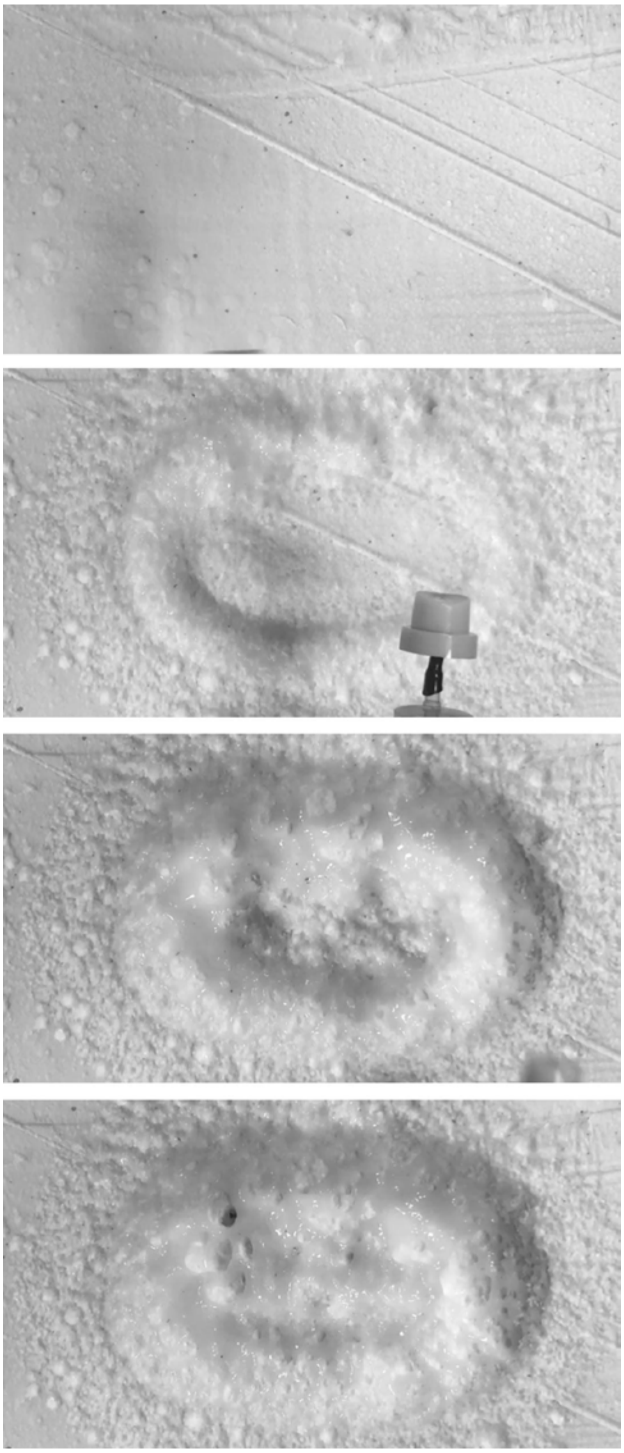


Figure.10 - Sequential images from fabrication process

4. Conclusion and Discussion

In the context of authenticity problem in numerical manufacturing processes, we argue that the concepts of ‘imperfection’, ‘trial-error’, ‘human subjectivity’ have potentials to provide a crucial ground for designers to test new, different and unexplored possibilities. An experimental design and fabrication flow called DFM to provide uniqueness in mass customization through programming and simulating the material (polystyrene) behaviour was designed and tested.

- Material studies and physical experimentation play an important role in designing customized tools and workflows. In this study, chemical transformations and their analysis have informed the calibration and design process of DFM. Utilizing chemical transformation on material led decrease of control over the fabrication process. As a result, DFM can be considered as formative fabrication process. However, the numerical manufacturing process can no longer address additive or subtractive fabrication process.
- Level of Detail (LOD) approach in the digital modeling simulated in a physical digital hybrid world. Macro scale decisions made digitally by the personal skills/aesthetics and micro scale details emerged by the medium of chemical properties. Material behavior is unpredictable in micro scale.
- Design of DFM covers the inseparable components of computation, subjective skills and material (properties) itself. A cooperation between computer, human and material. In other words, DFM involves integration of material, human and computation interaction in a dialogic way.
- There had been limited human factor during the design and development process of DFM. However, further to development of DFM, the workflow can result with unique qualities in surface finishing in each usage.
- The limitation of DFM is being a customized process. This is why, it is difficult to adapt it to different contexts. Due to linear recording feature of the methodology, the system does not allow real time material level manipulations. In the future studies it is aimed to improve this feature.

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