Design By Making

Enhanced Human-Computer Interaction for Digital Conception and Manufacturing in Architectural Education

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This paper presents an ongoing project which aims to develop an HCI application. The purpose of the application is to introduce tactile experience into digital design cycle and to have transparent links between different phases of the design object. Thus, it will provide a hybrid design environment in which design conception and manufacturing are integrated and enhanced learning opportunities towards an architectural education where making is fundamental.

Keywords: Human-Computer Interaction, Tactile Experience in Design, Architectural Education

INTRODUCTION

This ongoing project aims at developing a new Human-Computer Interaction (HCI) application to enable an enhanced and direct relation between the designer and the digital design environment. The application involves toolsets and methods which will enable the user to have a more organic relation with the design object during digital conception and manufacturing processes. Its functionalities are thought to be promising particularly for architectural education by enhancing the modes of communication in the design studio. It specifically considers the first year studio, where the essential approach is not to include complex architectural problems, but to introduce design as a broader concept while focusing on the fundamental aspects of architectural design, such as form, scale, space and materiality.

The intentions of the project are:

- To allow the designer directly interact with the design object through his/her body,
- To enhance the communication opportunities in the design studio and to allow and encourage its stakeholders collaborate on the design object,
- To extend the limits of the design studio as an environment of learning.

PROJECT BACKGROUND

The idea of this project initially stems from questioning the relation between the object of design and its representation. Schön emphasizes the significance of the representation tools in design and defines architectural design as an activity of producing the representations of the things to be built (Schön 1984). According to him, design is a reflection-in-action with talking backs which emerge as both the maker's spontaneous reflections and the reflections of the material back to the maker. What is missing in this very precious definition is that it lacks of the
possibility to include what is real instead of mere its representations into the design process. This project aims at extending this concept of “talking back” by including materiality into this definition of “reflective conversation”. It aims at questioning how it could be possible to manifest a practice of design which directly deals with what is material or real, instead of a mere focus on representation.

Chard seeks for a transparency between the thought and its projection and claims that the level of transparency is directly related with the capabilities of the tools used (Chard 2005). The concept of transparency is one of the core issues of this project and is aimed to be achieved between design thinking and different phases of the design object, such as the physical or digital models as well as the on-site product.

Therefore the idea of Design by Making refers to a process of design, where conception and manufacturing are merged together and the conversation is performed continuously and reciprocally between the physical and digital phases of the design object. This requires the re-introduction of the notions of craft and materiality into design process.

In architecture, the re-introduction of crafting as a mode in design development refers to relocating the architect back into the core of production, in contrast with industrialization which had pushed his/her position to a presenter of a practice which was held by others, a financial actor, or a rhetoric producer. This implication re-celebrates the value of crafts which was excluded from the practice of the architect by modernity and leaves more room free for what craft could bring into design.

The way we think is the property of a hybrid assemblage of brains, bodies and things (Malafouris 2013). And as Sennett mentions, what we can say in words may be more limited than what we can do with things (Sennett 2009). Including things and material particularities into design conversation will enable a more transparent media on which a more efficient design communication is possible. Dearden introduces the concept of material utterance which is a situated communication act that depends on the particularities of speaker, audience, material and genre (Dearden 2006). He claims that all materials have properties that moderate the ease or difficulty of creating a material utterance, like for different materials have different density, ductility, plasticity and malleability. It is important for the designer to experience these varying particularities which are intricate to each different material. This can only be achieved by tactile experience as all the senses including vision are extensions of the sense of touch and the senses are specializations of the skin, and all sensory experiences are related to tactility (Pallasmaa 1996). Therefore it is necessary to include this notion of material utterance with all its particularities into digital design cycle.

These notions are actually not exempt from digital design practices. The new techniques and methods of digitally enabled making are reaffirming the long forgotten notions of craft, resulting from a desire to extract intrinsic qualities of material and deploy them for particular effects (Kolarevic and Klinger 2008). Digital environment enables and encourages the integration of conception and manufacturing. Moreover, the common practice of representation is no longer valid, and the digital is now the real itself. What is seen on the screen is not the representation of the design object, but the objectified design idea itself. Its presence is yet in a unique phase, which still nestles all its material features and is always capable for phase transition. The geometric model seen on the screen, the parametric definition of the model, the prototype produced by the 3D printer or the digitized model produced by the 3D scanner are all different phases of the same objectified idea and are able to transform into each other instantly.

Design, in this manner, performs an exciting similarity with vernacular forms of making. Here, just like in vernacular, making and design are integrated practices and the maker’s direct relationship with the object is essential. However, the difference is that a direct bodily relation is yet not fully sufficient.

On the other hand, by the introduction of in-
formation and communication technologies (ICT), a strong paradigm shift has occurred in architectural education too. This paradigm shift has implied a significant awareness in academia and altered the expectations from education. The school is no longer an institution of didactics, but an enhanced environment of research and experience. The rising influence of novel concepts, such as Maker Culture, Hackerspace or Fab Labs, forces architectural education to have a stronger emphasis on learning rather than teaching. Even though these phenomena are not entirely new, the developments in ICT and the spread of digital culture make them the de facto bases of learning and production for the future practitioners. Hence, the school needs to be an environment where the necessary facilities and encounters which are necessary for enhanced learning are provided. This refers to enhancing the possibilities of communication and encouraging making in the design studio.

The application which is presented in the next chapters is being developed towards these principals in order to enhance the already existing possibilities provided by the digital media, enabling the designer have a more direct and organic relation with the design object, integrating design conception and manufacturing, including the notions of materiality and crafting, and utilizing this new experience for enhanced learning in architectural education. The application is a proof of concept, and currently being developed. It is still necessary to include more features, test its functionalities with architecture students, and conduct an in-depth theoretical discussion in relation with the project principles.

APPLICATION ENVIRONMENT

3D Motion Detection
The application runs with Leap Motion Controller, a three dimensional motion detection device. It tracks the three dimensional movements of hands, fingers and certain tools without a physical touch and uses them as input to digital applications. The reason for choosing Leap Motion Controller for this project is that it is more precise in detecting the hand movements, it provides a more user friendly Software Development Kit (SDK) which supports several programming languages including JavaScript, it is cheaper, smaller, lighter and is easier to operate with, comparing with similar devices on the market.

There already exist several applications which use the controller for HCI in different fields such as gaming, healthcare, education and data visualization. In this project, motion detection is thought to be a promising opportunity to include tactile experience into design process. There could have been three different approaches of application development to include motion detection into digital design applications:

1. Developing a standalone application.
2. Developing a plug-in which operates with the existing CAD software.
3. Developing an application which allows customized desktop control.

A standalone application would offer a more flexible and independent solution. However this is not the aim of this project because resource and time wise it is not seen efficient to develop CAD software from scratch instead of utilizing an existing one. Therefore the aim is to develop a customized desktop control application in the first phase, then to develop a plug-in for existing CAD software in the second phase. In this sense, the project utilizes the existing technology; and its innovative aspect is to build up new methods for using the technology and new relations between the tools.

CAD Software
The project is developed on SketchUp Make 3D modelling software. The reason for choosing SketchUp Make is that it is for free, is easy to learn and use and it supports Ruby application programming interface (API) which is fairly more user friendly when compared to other available interfaces. Moreover, modelling in SketchUp Make is mostly intuitive, which is a feature that makes it a proper environment in relation with the project aims.
APPLICATION FEATURES
Several features are gradually being included in the application for the integration of conception and manufacturing in design. Eventually it aims at providing a toolset to be utilized in all phases of digital design cycle. The features are as follows:

- Imaginary Tactile: Provides 3D digital modelling by using hands.

- Simultaneous Physical Modelling and Digitizing: Provides physical modelling and simultaneous digitizing by using hands and certain tools.

- Simultaneous Design and Making: Provides link between the digitized model and robotic manufacturing.

- Tool Variety in Motion Scanning: Provides a variety of tools to be used with the controller.

In this project it is aimed to develop only the first two features. The other features are going to be developed as separate projects. The outcomes of the first feature and the context and aims of the second feature are presented in this paper.

Imaginary Tactile
This feature allows the user to build a digital 3D model and modify it by using his/her hands, where both hands can operate simultaneously (Figure 1). There already exist a couple of applications which integrate the controller with CAD software, such as AutoCAD and Leap Motion Integration, Ossewa SolidWorks Plug-in, Leap Motion for Grasshopper and Leap Motion Plug-in for Autodesk Maya. These applications utilize the controller analogues to a mouse. Also, there are a couple of applications which experiment utilizing the controller on SketchUp. They utilize a third party application such as Touchless, AirInput or GameWAVE to interact with SketchUp by providing an alternative to a mouse. These applications are for controlling the desktop therefore can interact with any software with varying degrees of functionalities. Likewise, the Imaginary Tactile feature allows the user interact with SketchUp through a third party desktop control application which gets input from the controller (Figure 2).

The most important challenge for this feature is to customize the hand gestures and define the relations between the hand gestures and the software functions in the best possible way in order to provide a seamless workflow. In other words, the existing ways of desktop interaction with the controller need to be tailored for 3D modelling in SketchUp. For this purpose, the GameWAVE application is chosen to be modified as it allows easier and more efficient configuration. Eventually, two different configurations with different modes of interaction are developed:

- Imaginary Tactile with 2 Modes
- Imaginary Tactile with 3 Modes

Imaginary tactile with 2 modes. This configuration mediates the mouse movements and clicks, as well as the Pan, Orbit, Zoom, Undo and Select functions of the software by using the controller. The idea is to let the user reach any function of the software in a mouse-like fashion, while letting him/her run certain Camera and the most used Tools and Edit functions as
### Table 1
Gestures and functions for the first two modes of the Imaginary Tactile configuration.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Function</th>
<th>Mode (T/S)</th>
<th>Hand (L/R)</th>
<th>Gesture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mouse</td>
<td>Move Up</td>
<td>Steering</td>
<td>Right</td>
<td>Move/Upward</td>
</tr>
<tr>
<td>1 Mouse</td>
<td>Move Down</td>
<td>Steering</td>
<td>Right</td>
<td>Move/Downward</td>
</tr>
<tr>
<td>1 Mouse</td>
<td>Move Left</td>
<td>Steering</td>
<td>Right</td>
<td>Move/Leftward</td>
</tr>
<tr>
<td>1 Mouse</td>
<td>Move Right</td>
<td>Steering</td>
<td>Right</td>
<td>Move/Rightward</td>
</tr>
<tr>
<td>1 Mouse</td>
<td>Left Click</td>
<td>Steering</td>
<td>Right</td>
<td>Thumb/Lift</td>
</tr>
<tr>
<td>1 Mouse</td>
<td>Double Click</td>
<td>Steering</td>
<td>Right</td>
<td>Finger/Tap</td>
</tr>
<tr>
<td>1 Mouse</td>
<td>Right Click</td>
<td>Steering</td>
<td>Right</td>
<td>Incline/Outward</td>
</tr>
<tr>
<td>1 Editor</td>
<td>Escape</td>
<td>Steering</td>
<td>Right</td>
<td>Incline/Inward</td>
</tr>
<tr>
<td>1 Editor</td>
<td>Undo</td>
<td>Steering</td>
<td>Right</td>
<td>Rapid/Multi Taps</td>
</tr>
<tr>
<td>2 Tools</td>
<td>Select</td>
<td>Trigger</td>
<td>Left</td>
<td>Incline Closed/Outward</td>
</tr>
<tr>
<td>2 Camera</td>
<td>Pan</td>
<td>Trigger</td>
<td>Left</td>
<td>+Fingers/Swipe Left &amp; Swipe Right</td>
</tr>
<tr>
<td>2 Camera</td>
<td>Orbit</td>
<td>Trigger</td>
<td>Left</td>
<td>+Fingers/Circle Left &amp; Circle Right</td>
</tr>
<tr>
<td>2 Camera</td>
<td>Zoom</td>
<td>Trigger</td>
<td>Left</td>
<td>Incline Closed/Upward &amp; Downward</td>
</tr>
<tr>
<td>1&amp;2 Tools</td>
<td>Switch Mode</td>
<td>Steering &amp; Trigger</td>
<td>Right &amp; Left</td>
<td>(SR)Rapid/Multi Taps &amp; (TL)Rapid/Multi Taps</td>
</tr>
</tbody>
</table>

### Table 2
Gestures and functions for the third mode of the Imaginary Tactile configuration.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Function</th>
<th>Mode (T/S)</th>
<th>Hand (L/R)</th>
<th>Gesture</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Draw</td>
<td>Line</td>
<td>Steering</td>
<td>Left</td>
<td>Move/Upward</td>
</tr>
<tr>
<td>3 Draw</td>
<td>Rectangle</td>
<td>Steering</td>
<td>Left</td>
<td>Move/Downward</td>
</tr>
<tr>
<td>3 Draw</td>
<td>Circle</td>
<td>Steering</td>
<td>Left</td>
<td>Move/Leftward</td>
</tr>
<tr>
<td>3 Draw</td>
<td>Arc</td>
<td>Steering</td>
<td>Left</td>
<td>Move/Rightward</td>
</tr>
<tr>
<td>3 Tools</td>
<td>Push/Pull</td>
<td>Steering</td>
<td>Left</td>
<td>Thumb/Lift</td>
</tr>
<tr>
<td>3 Tools</td>
<td>Move</td>
<td>Steering</td>
<td>Left</td>
<td>Finger/Tap</td>
</tr>
<tr>
<td>3 Tools</td>
<td>Rotate</td>
<td>Steering</td>
<td>Left</td>
<td>Incline/Outward</td>
</tr>
</tbody>
</table>
well as the *Escape* and *Switch Mode* functions by hand gestures. For this purpose, the assigned functions are categorized as stable (Trigger Mode) or active (Steering Mode) functions and they are associated with certain gestures of the right or left hand, where the right hand mediates the active functions and the left hand mediates the stable functions (Table 1). It is important that the selected gestures should be intuitively sympathetic with the assigned function.

This configuration allows a more organic interaction with the digital environment comparing with mouse use, because the use of the hands in 3D space provides a more efficient perception of the form. However, the transparency between the designer and the object is not yet in the desired level. Because, the designerly logic behind the held operations is not much different than what the common practices include. Therefore the only progress achieved with this configuration is the gained ability of using the hands in a 3D fashion, especially for model viewing functions, and the fun and excitement brought with this new experience.

**Imaginary tactile with 3 modes.** This configuration is achieved by enriching the previously used two modes with the left hand trigger mode. The idea behind providing one more mode is to allow the user to access certain functions of the software by using hand gestures instead of pointing them on the toolbar. This new mode provides access to the *Line*, *Rectangle*, *Circle* and *Arc* functions of the *Draw* menu, and the *Push/Pull*, *Move* and *Rotate* functions of the *Tools* menu by using hand gestures. Similar to the interaction with 2 modes, the categorization of the software functions and their association with the hand gestures through an intuitive manner are essential within the configuration (Table 2).

Interaction with 3 modes provides a more organic relation between design thinking and the design object comparing with the use with 2 modes. Because the user does not need to point the tools on the toolbar for the most commonly used functions of the software, but he/she activates them by performing hand gestures. Therefore this configuration provides an experience in which the designer feels like he/she uses not only his/her hands in the 3D space, but also certain tools even though the feeling is imaginary.

On the other hand, the functions that are available through hand gestures are limited because the GameWAVE offers a limited number of gestures to be customized. So that the user still needs to point the tools on the toolbars or in menus to reach many functions of the software. Also, the hand gestures provided for customization by GameWAVE are all predefined. Therefore a perfect intuitive relation between the sought function and the hand gesture cannot always be obtained. Because of these reasons, the *Imaginary Tactile* feature can prove the concept of *Design by Making* only up to a certain limit. As a concept, it is able to prove that; a more organic relationship between the designer and the digital design environment can be achieved with the existing technology, the use of hands in 3D space provides a more transparent media between design thinking and the design object, the bodily actions provide a more direct interaction with the object during the design process, and such an enhanced interaction with the digital design environment is fun and exciting.

The next phases of the project focus on the missing aspects which are necessary to develop a stronger proof of the concept of Design by Making.

Figure 3
Simultaneous Physical Modelling and Digitizing
Simultaneous Physical Modelling and Digitizing

The purpose of this feature is to eliminate the distance between the physical design object and the digital one (Figure 3). The common practices of digital design and manufacturing involve sequential steps such as the generation of the digital model first, then its physical manufacturing. In the cases which require further digital processing of the physical model, a digitizing process, which usually is operated by 3D object scanning, is executed (Figure 4).

This feature is developed in order to achieve a process in which the production of the physical model and its digitizing is simultaneous. Instead of scanning the completed physical object, its production process is scanned by tracking the operations of the working hands and tools. Thus, the physical and digital phases of the design object are produced simultaneously, and the concept of "reverse engineering" becomes an internal component of the design process (Figure 5).

This feature requires the tracking of the tools as well as hands used in the physical production as hands are not always enough to work on a physical object. Currently, the controller can recognize and track long, thin and straight objects such as a pencil. In order to be able to involve the several types of objects used in physical manufacturing, more developed motion detection devices are necessary. This is going to be the focus of the later phases of this project, whereas the current aim is to utilize the existing capabilities of the device for this purpose.

The idea of using a 3D printing pen or a glue gun is thought to be applicable for the current phase, as it is possible to build 3D physical objects with these tools and to track them using the controller. 3Doodler Pen is evaluated as the best tool to be tested, as it is proved to be stable and precise enough to build physical objects and its form is similar to a pen, which makes it easier to be recognized by the controller.

3Doodler Pen is a 3D printing pen that melts and then cools plastic thread while the pen is moved in 3D space. It uses ABS or PLA plastics like the common 3D printers. One can see it as a freehand and manual 3D printer, as it provides additive manufacturing and uses similar types of materials like 3D printers. However, unlike a 3D printer, the production of the object with this method is not in a layer by layer fashion, but more visual and depictive. There is no digital data used for physical production. On the contrary, with this feature of the project, this production method is used as a mode in which the intuitive and depictive behaviours of the designer are transformed into digital data in order to produce the digital phase of the design object.

It is possible to provide the feature of simultaneous physical modelling and digitizing by two different approaches. The first approach would be using a desktop control application like in the previous feature. The GameWAVE application does not track objects; therefore it is necessary to develop a new application for desktop control which can track hands and the 3D printing pen simultaneously. The second approach would be providing the same functionality by a plug-in which specifically works with SketchUp. Currently the application performs as a separate customized desktop control application.

The most important aspect of this feature is that the controller tracks the movements of the pen while building the physical model and this input is used to produce the digital model simultaneously. Therefore the procedure of the digital production should be convenient with the way the pen is used. In other words, the logic behind the production of the geometry should be identical for both the physical and the digital modes. Considering the use of the pen, this convenience can be achieved by the Line and Freehand functions of the software. Both geometric elements are defined in the same way, by tracing of the pen tip for the physical model, and by tracing of the cursor position for the digital model. Therefore the controller tracks the movements of the pen in the physical 3D space and accordingly moves the cursor position in the digital 3D space. However, during physical modelling, the pen is moved not only to build the geometry but also to reposition. Therefore
Figure 4
The workflow in the common practices of digital design

Figure 5
The complete digital design cycle
it is necessary to activate and deactivate the functions during the pen movements in order to avoid building excessive geometric elements in the digital model.

The application is developed in JavaScript using the Leap Motion SDK. Currently, only two modes are developed in order to keep it as simple as possible until the tracking of the pen reaches a robust level. The modes currently available are:

- Pen mode: controls mouse movements to trace the geometry for the digital model,
- Hand mode; controls Line, Freehand and mouse left-click by using 3 different gestures.

This feature is not yet robust enough because of a couple of problems which are gradually being solved. The main problem is that the size and shape of the 3D printing pen is slightly out of the limits of what the controller can track. Until the controller is developed to be able to track the 3D pen or another 3D printing pen which has a size and shape within the limits is possible to be used, the application algorithm performs the task by tracking a certain point on the hand which holds the pen instead of the pen itself. The other problem is that the controller's sensors are directed upwards when it is in its standard operating position and it can most effectively track the hands and tools within a limited field of view which is above the device. In order to keep the controller in its standard position and operate the physical modelling within the field of view, a glass surface is put above the controller and used as the base for the physical model.

The firsts tests executed using this application provides good enough results to see the direct relation between the physical model and the digital one. However, currently models are not entirely identical. This is mainly because of the sensitivity difference between the digital and physical environments. This results excessive geometric elements to appear in the digital model and will be solved by developing the application algorithm. Also, certain movements of the hand are tracked on wrong axes because of the axis recognition algorithm of the software. The best solution to avoid this problem is to develop the application as an embedded plug-in in further steps. So that it can communicate with the software algorithm in the best possible way.

Yet, the application is currently good enough to prove that the idea of Design by Making is applicable and such a direct relation between physical modelling and digital modelling is promising and can be developed further.

CONCLUSIONS

The application which is being developed in this project provides a new design experience where conception and manufacturing are integrated and reciprocal feedbacks between different phases of the design object are performed continuously. It reintroduces the notion of craft into design process. It allows the designer have a sense of tactile experience where design development is performed on the design object itself instead of its representations. It provides a transparent link between different phases of the design object and different types of media. It can also be seen as a hybrid facility for sketching, where the outcomes of sketching are both physical, digital and three dimensional, as it is a natural way for the designer to explain and understand complex ideas and to perform visual and spatial reasoning as defined by Do (Do 2002).

One can also argue that these features will provide an enhanced learning environment in architectural education. In the common practices of digital design, design development is performed distinctly in digital environment which is treated as a representational media. This results the lack of fundamental aspects of architectural design such as materiality and scale in design thinking, particularly from the students' point of view. This application proves that it is possible to recall these aspects by literally putting the hands and tools into the digital environment.

Moreover, such a practice of design will enhance the possibilities of communication between
the stakeholders of the design studio. The common practice is based on a process where the student develops a solution to the given design problem, presents it through representation tools, and receives verbal comments and evaluations upon it. Learning is by the student's own practice, observing the other students' practices, and by receiving verbal critics from others. With the help of this application, it will be possible to work collaboratively on the design object itself. As the application can track more than two hands and tools simultaneously, not only more students, but also teachers can actively participate in the design development. The collaboration can even be distant by using an online shared digital model (Figure 6). Therefore an efficient environment of making can be achieved which will profoundly introduce the concept of Maker Culture into architectural education.

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