**Augmented Reality and the Fabrication of Gestural Form**

**Introduction**

The inherent link between technological development and architectural design innovation is one of both empowerment and restriction. As William Mitchell poignantly observed, “architects tend to draw what they can build and build what they can draw” (2001, cited Kolarevic 2003). While industrial robotic manipulators have recently provided the potential of highly informed (Bonwetsch et al., 2006) design fabrication, a coupling of these technologies with developments in accessible representational techniques would enable another means of informing design for mass customization (Piller 2004). Mario Carpo (2001) illustrates that, while design and construction technologies are clearly linked to the development of architectural styles (trabeation for the Ancient Greek, the arch for the Romans, stereotomy for the Gothic, reinforced concrete in modernism, and more recently, digital fabrication), they can also be influenced by technologies of representation and the dissemination of media (notably, the effect of the printing press upon the Renaissance).

With the prominence of social networking, Web 2.0, and highly-capable smart phones, new forms of representational media have become more fluid and, in turn, accessible to designers. In this paper, we examine a series of experiments which utilize a combination of representational and fabrication techniques with potential utility in on-site architectural design and mass customization. Namely, we develop a low-cost augmented reality (AR) system using widely available commercial products for use in a workflow in which forms are generated using skeleton-tracking and human gesture, previewed using a see-through AR headset, and fabricated in situ via robotic manipulator.

**Related Work**

There have been numerous research projects involving gestural form-finding (Greenwald, 2003) and many more that suggest the potential application of augmented reality systems in architectural design (Feiner et al., 1996).

The intent of this research is not to develop or dwell upon technology in skeletal tracking or augmented reality, but rather to implement them as simply and as cheaply as possible in order to explore their ability to inform architectural design, robotic fabrication, and mass customization. In this sense, the project contains some of the same ideas behind the cell-phone-designed mTable of 2002 (Gramazio and Kohler, 2008)—by empowering non-designers with software that turns their own off-the-shelf hardware into highly capable and often clumsily-controlled design tools, architects are forced to rethink their role in a world where digital fabrication technologies have enabled the potential of mass-customization.

**Initial Research**

This project naturally evolved from research begun at the Gramazio & Kohler Professorship for Architecture and Digital Fabrication, ETH Zurich, which explored the on-site potential of robotic fabrication through the use of laser scanning technologies and a robotic manipulator mounted on a mov-
Augmented Reality and the Fabrication of Gestural Form


Augmented Reality System

Overview

While the potential of coupling the gesture recognition of the Kinect with robotic manipulators has been explored on numerous occasions, there is generally a gravitation towards human mimicry via telerobotics (De Luca and Flacco, 2012; Itauma et al., 2012) rather than utilizing gesture as guiding factor for more complex processes (i.e. brick laying). By combining the highly informed detailing made possible by computer scripting and industrial robotics with gestural inputs, defining complex structures intuitively on-site becomes more feasible.

In order to experiment with the potential of shaping, interacting with, and approving the parameters of gesturally-based forms in situ prior to robotic fabrication, we opted to utilize a see-through, head-mounted augmented reality system.

To maximize options for expanded functionality and to avoid the cost of AR-specific commercial products, we developed our own device using cheap, off-the-shelf components.

Hardware

In searching for the components necessary for an augmented reality system—position tracking, orientation sensors (electronic inclinometer/accelerometer and compass), networking communications, portable power, resolute screen, and an operating system that supports localized software (Feiner et al., 1997)—it quickly became clear that all of these elements were available inside the majority of today’s smartphones. Repurposing such a widely available product ensured low cost, compact form-factor and the potential of making any developed applications accessible to a mass audience. For its existing integration with the processing environment [4], the Android OS became the core of the augmented reality system.

Multi-device Interface

By creating a custom interface between three mass market electronic devices (Kinect, personal computer, and smartphone), we are able to create a robust gestural interface using components that exist within millions of homes worldwide [5]. The interconnectivity of the devices functions in the following manner (Fig. 3):

1. Both the PC and Droid X (headset) are running custom applications written in processing which are constantly communicating with one another wirelessly over the internet using OSC protocol [6].
2. The Kinect is connected via USB to the PC and provides the data used for 3D tracking of the user’s joint coordinates.
3. Head pan, tilt and roll are calculated using the mobile phone’s accelerometer and geomagnetic sensor [7], while head position is read from the Kinect data.
4. The touch screen of the Droid X activates the software.

Figure 1 Brick wall robotically fabricated along gestured path. Gramazio & Kohler, ETH Zurich.

Figure 2 Smartphone based augmented reality headset. Equirectangular image credit: Ilja van de Pavert.
Augmented Reality and the Fabrication of Gestural Form

Prototype build process.

Figure 6

Interface of hardware and software for gestural AR system.

Figure 3

Augmented Reality and the Fabrication of Gestural Form
Irregular Substrate Tiling

For the construction of this prototype, we accessed a salvaged mini-fridge compressor and to a solenoid valve which can release by the robot controller is wired to a relay which controls power to the compression system of the robot controller is wired to a relay which controls power to the compressor. The I/O interface and referencing them during the coordinate values to Rhino Python via serial processing.

The program on each device is equipped with the same expandable set of gestural form-finding techniques: at the current state of this prototype, the primary functions are “loft” surfaces and “brick” surfaces. All commands are accessed by tapping the touch-screen to initialize voice recognition, and then speaking the command (which is registered by the Droid and immediately sent to the pc). In example, the spoken command “loft” initializes the generation of a surface that is lofted between the paths of the right and left hand, while the command “brick” initializes a brick wall which follows the path of the right hand in plan and is built to the height of the hand in elevation.

Multiple functions can be run simultaneously (Fig. 5a), forms can be added to or erased, and multiple objects can be generated within the same program. The user can walk around and explore the scene before speaking the command “Rhino” to open the exported geometry in the 3d modeling software (Fig. 5b) on the pc for prototyping (Fig. 5c), or can export RAPID for direct use with the robotic manipulator (Fig. 6).

Discussion

While augmented reality systems and gestural form-finding are certainly not new topics, we propose that their architectural potential is reinvigorated through integration with industrial robotics and the question of design scale. If we regress to the time of the primitive hut, we find an architecture that is both designed and con-

Figure 4

Orientation-responsive equirectangular image viewer developed with processing for Android.

Figure 5

From left: a) Simultaneous gestural generation of brick wall and loft surface using hand coordinates. b) Geometry exported to Rhino 3d. c) Lasercut scale model.
In this paper, we implement a workflow in which architectural forms can be generated based on bodily movement, previewed and altered using an augmented reality system, and translated back into the physical world through means of digital fabrication. Using a prototypical software interface, we present a method for adding informed complexity to spontaneous forms. In this instance, we generate a brick wall or a loft surface along the path of the hand, but foresee a potential future in which design functions could be added by other developers and architects much like “apps” are added to smartphones. In this way, the software could be expanded to enable a wide array of modeling techniques which are tailored to consumer demands or specific developments in computational design and fabrication technologies. By providing individuals with intuitive means for roughing out architectural forms at the human scale, and then equipping them with easy techniques for exploring, editing, detailing and fabricating those forms, such interfaces make the design process more accessible to non-architects. The potential implications of mass customization, therefore, can only be realized when the technology for representing and disseminating design options is given as much attention as the tools for fabricating them.

Acknowledgements

This research owes much to the Gramazio & Kohler Professorship for Architecture and Digital Fabrication, ETH Zurich for their kind support during my research stay, and to the ThinkSwiss Research Scholarship for their funding during that period. I would like to thank Axel Kilian for being supportive of my research, Alejandro Zaera-Polo and Ryan Welch for their valuable criticism and insights regarding the augmented-reality headset and interface, and Nicholas Foley for his partnership in developing greyshed.

References

ABB Robotics AB, 1997 RAPID Overview, Väststräs, ABB Robotics AB, Vol. 3, PACE 577-4 for BaseWare DS 3.2.
Greenwell, S 2003 “Spatial Computing”, Graduate School of Science in Media Arts and Sciences, Massachusetts Institute of Technology, Massachusetts.
Kwiatek, K 2005 “Generation of a virtual tour in the 3D space applying panoramas, exercised on the sites of Dresden and Cracow”, Thesis (Diploma), AGH University of Science and Technology.