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Augmented Reality and the Fabrication of Gestural Form

Abstract Architectural design is developed in conjunction with technological innovations. These developments are not merely informed by new tools and techniques of production, but also by technologies of representation and dissemination (Carpo 2001) . The last decade has seen a marked increase in both realms: parametric design, CAAD (Computer Aided Architectural Design) and CAM (Computer Aided Manufacturing) on one side, and networked mobile visualizations on the other (augmented reality, smart phones, Microsoft's Kinect technology, Web 2.0, etc.). In this paper we utilize a combination of these technologies to explore the design potential of using robotic fabrication tools in conjunction with a specially developed low-cost augmented reality system. We propose and implement a work-flow in which forms are (1) generated using skeleton-tracking and human gesture, (2) visualized, explored and modified in 3D first-person-view in situ with a head-tracked see-through augmented reality headset, and (3) fabricated in position using a robotic manipulator. We will discuss the communication protocol behind several variations of this procedure and their architectural implications upon design scale, on-site design, and the modular.

Keywords: Augmented Reality; Digital Architecture; Robot Programming.

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 (Greenwold, 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 cellphone-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 movable platform. Initial tests utilized a robot-mounted *Kinect* (Kean et al., 2011) scanner connected to a nearby PC, which was in-turn connected to the robot controller via Ethernet connection. Using the *simpleOpenNI* [1] library for *processing* [2], we were able to track the 3D hand coordinates of the human user in real-time. The program was written such that hand movements could be interpreted to generate a virtual brick wall along the gestured path as it was drawn. By reading the orientation and position of the robotic manipulator, the *Kinect's* local coordinates could be transformed to match the coordinate system of the robot, and the processing code was written such that the generated brick positions and orientations could be translated into the native language or the robot (ABB, 1997) and sent directly to the controller. Using a vacuum gripper attached to the same end-effector as the *Kinect*, the robot could then proceed to construct the brick wall along the designated path (Fig. 1).

For more information on this research project, see “In-situ robotic fabrication” (Project leader: Volker Helm; Collaborators: Dr. Ralph Bärtschi, Tobias Bonwetsch, Selen Ercan, Ryan Luke Johns, Dominik Weber), Professorship for Architecture and Digital Fabrication, ETH Zurich [3].

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.

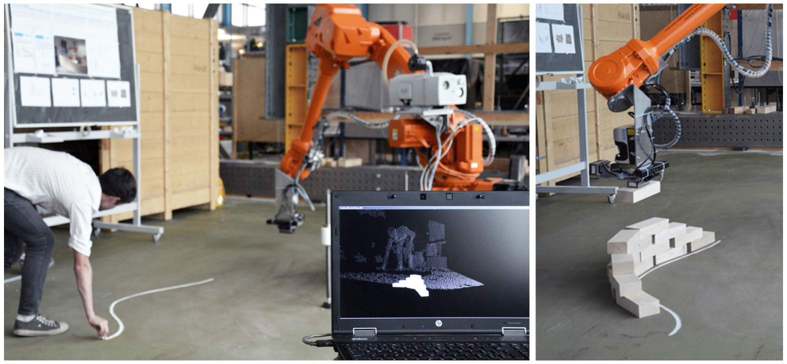

Figure 1 Brick wall robotically fabricated along gestured path. Gramazio & Kohler, ETH Zurich.

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), networked 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 was selected and a used *Motorola Droid X* became the core of the augmented reality system.

The headset was assembled from the hardware of a scrap head-lamp and laser-cut acrylic parts, with the *Droid X* mounted above the eyes with downwards-facing screen, reflecting onto an angled sheet of transparent, mirrored acrylic (Fig. 2).

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

Figure 2 Smartphone based augmented reality headset. Equirectangular image credit: Ilja van de Pavert.

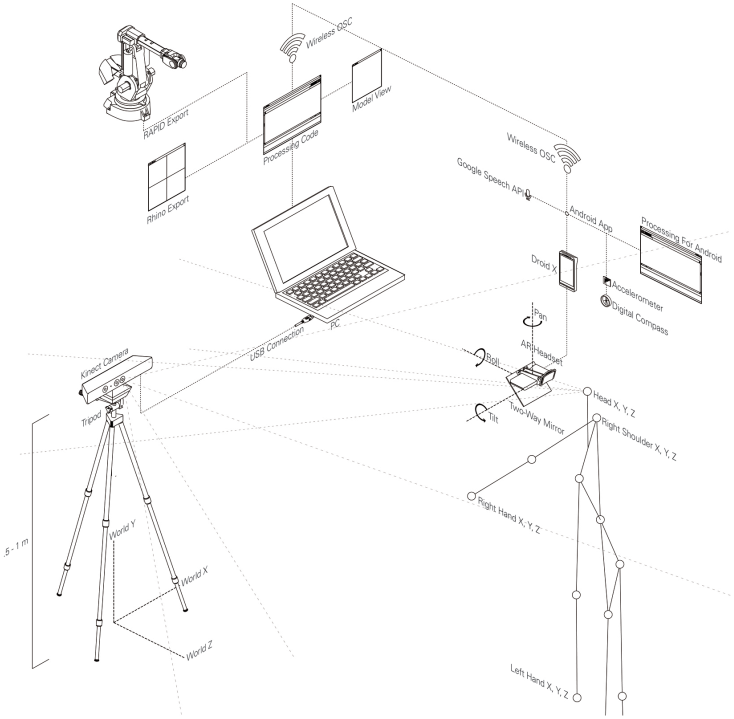

Figure 3 Interface of hardware and software for gestural AR system.

Google's Speech Recognizer [8] to listen for voice commands which operate the program.

Software Development and Capabilities

In order to gain familiarity with *processing for android* and an understanding of how to utilize the phone's sensor readings, we first implemented a simple panoramic viewer which rotated the viewing direction within a textured sphere [9] (mapped with an equirectangular image) based on the user's head orientation (Kwiatek, 2005) (Fig. 4).

Once we were familiar with the settings required to create a fixed position, orientation-based viewer, these techniques were combined with the skeleton-tracking capabilities of the *Kinect* order to enable a fully navigable and modifiable AR environment.

The software on the PC side reads skeleton data, and is constantly sending the head and hand positions wirelessly to the headset. The *processing* 'scenes' in both versions of the software are fundamentally the same—sharing a common world origin directly below the *Kinect* on the ground plane. The headset software merely places its virtual camera at the received head-XYZ coordinate and orients the camera frustum based on the values read from the accelerometer and compass. As head-rotation (in plan) is based on world azimuth angles and the *Kinect* is not always placed due-north of the viewer, each session begins by the user facing the *Kinect* and "calibrating" the scene such that the angle between the calibrated azimuth and true-north is factored into future camera rotations.

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).

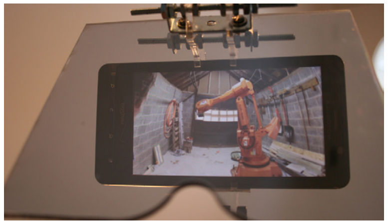

Figure 4 Orientation-responsive equirectangular image viewer developed with processing for Android.

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-

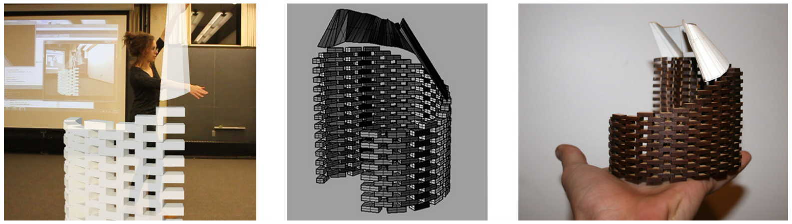

Figure 5 From left: a) Simultaneous gestural generation of brick wall and loft surface using hand coordinates. b) Geometry exported to Rhino 3d. c) Lasercut scale model.

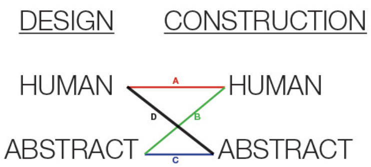

Figure 7 Relationships between scales of design and construction in architecture.

structed at the human scale (Fig. 7a)—one that is informed by the modularity of man and restricted by the strength and reach of his body. As drawing technology entered the picture, however, architects began to design at abstract scales while construction detailing remained limited by the capabilities of the worker (Fig. 7b). With the advent of computer modeling and industrial fabrication, both architecture and construction have lost their association to the human body: digital models are generated in abstract scales and fabricated using machines whose scale, strength and precision go far beyond human potential (Fig. 7c). We suggest that a coupling of gestural form-finding with highly capable industrial robotics enables an exploration of the last remaining trajectory: one in which design is done at a human scale and construction is performed with a level of strength and complexity that is entirely inhuman (Fig. 7d).

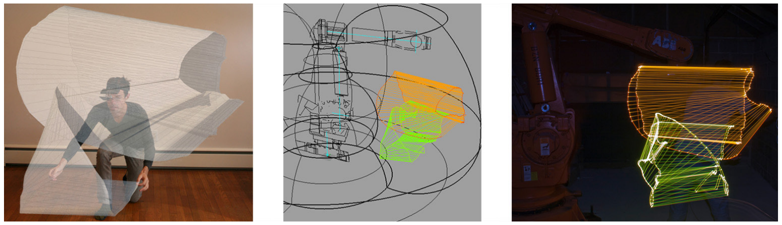

Figure 6 From left: a) Loft surfaces generated using AR headset and hand coordinates from the Kinect. b) Surfaces exported to Rhino for viewing. c) RAPID code generated for robotically produced light painting of surface.

Conclusion

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 presenting and disseminating design options is given as much attention as the tools for fabricating them.

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[5] http://community.guinnessworldrecords.com/_Kinect-Confirmed-As-Fastest-Selling-Consumer-Electronics-Device/blog/3376939/7691.html.

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[8] http://developer.android.com/reference/android/speech/package-summary.html.

[9] http://processing.org/learning/library/texturedsphere.html.