EMBODYING ARCHITECTURAL FORM AND SPACE BY COUPLING COMPUTER AND HUMAN PERFORMANCE USING MOTION CAPTURE TECHNOLOGY

Study on Application of Motion Capture to Design Process for Generating New Geometry

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Abstract. This research aims to develop fundamental design methodologies for human space and product design by motion capture of human activity. It is intended to generate new geometry using a motion capture system as design input device and then to develop it to design interior space and products such as furniture from data extracted from human motion. In order to produce a ubiquitous and comfortable environment, performance modeling focusing on the relationships between space and physical motion is needed. Making an object of complex shape is thought to be a new application of motion capture technology. This research proves that the numeric data of body actions can be transferred and developed to object shapes.

1. Introduction

The purpose of this research is to develop fundamental design methodologies using motion capture technology that will help generate new architectural forms and spaces that are not possible using conventional design methodologies and processes. Characteristics and feasibilities of the forms and spaces extracted from human performance and reconstituted by the proposed methodology are to be examined.

1.1. MOTION CAPTURE FOR DESIGN

Motion capture is a technique of digitally recording movement in 3D by detecting optical markers worn by an actor/performer. It is currently used mostly in animation tools for gaming programs and movies, and in sport sciences, manufacturing, and medical disciplines. It is rarely used, however, in the field of architecture and product design as an object data input device, and here the use of motion capture has been limited to rationalizing and optimizing space for human actions such as car driving. Most of the research using motion capture is in the visual disciplines and related disciplines. As early as the 1980s, the MIT Architecture Machine Group experimented with optical tracking of the human body for the design of space and the study of ergonomics (Sturman, 1994). The potential of motion capture and tracking has been demonstrated as follows:

- in the design of automobiles (Stephens, 2006) and for the *Kaizen* or improvement of automobile production (Koriyama, 2006, and see Figure 1 below),
- for the development of virtual environments and simulation of human action in the virtual environments (Caputo, 2007),
- for designing assistive devices for physically challenged and aging populations (Kumar, 1997),
- for capturing, analyzing, and archiving traditional dance performance (Yamura, 2002), and
- for development of highly customized products and simulation of their manufacturing process (Tseng, 1998).

Figure 1. Evaluation and improvement of automobile production line

As seen in the above, there is a lot of research involved in extracting and analyzing human action in the fields of robotics, virtual reality, and health care, and in line with recent development of computer technology many of the applications are now actually in use. Motion capture is rarely used as a design device, however. While it is used to analyze human action to develop kitchen design (TOTO), it mainly focuses on areas of action and rationalizing action, and it is hard to say that it is related to the design of the kitchen directly. There is one case that uses motion capture as a direct design input device, called Sketch Furniture by the Swedish design group FRONT. They experiment with motion capture to design virtual furniture (such as tables and chairs in the air), and with rapid prototyping to embody virtual furniture. Unlike the ordinary process by which furniture is materialized through design studies using 2D drawings and models, in their process trajectories that their hands draw are directly transferred to the shape of furniture, which has a one-of-a-kind nature produced out of their interaction with the space. But this is one of the rare cases of trying to generate forms directly using motion capture for design.

Motion-capture-related tools include Shape Tape. Instead of markers, it uses optical fiber that is attached to the human body and generates virtual shapes in real time on the computer. This allows tracking human action not by points but by lines.

1.2. RESEARCH BACKGROUND

From this overview of the applications of motion capture technology to design, it is possible to say that it is rarely used in the field of architecture and product design to lead to the objective design of products. Research and projects on motion capture are usually about simulating how human action can be efficient or how operability can be improved under somewhat restricted conditions or how existing processes can be streamlined, such as by the use of rotoscoping animation (Sturman, 1994). In the architectural discipline, it also focuses on how to remove unnecessary action and sources of danger rather than directly capturing human action and generating geometry out of the captured data.

The present research aims to develop fundamental design methodologies for architectural and product design involving motion capture technology. In addition, in the current process from design to production, some parts of the user's needs for the product may be missed or modified during the course of the process, particularly when the designer translates the user's design requirements (Figure 2). If motion capture can directly translate the user's needs that are based on her/his conditions and mobility into physical forms, it may be possible to minimize the chances of missing information. It is also intended to examine the difference between the shapes generated by intentional and arbitrary actions.

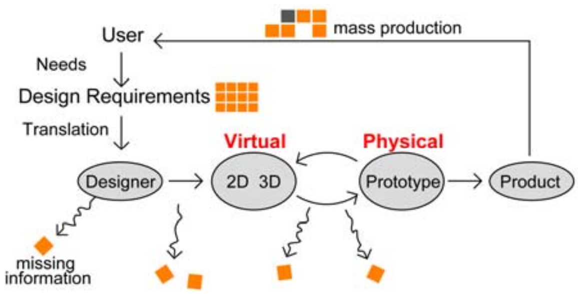


Figure 2. Current process: some information may be missed or modified

1.3. RESEARCH MODE

In order to embody architectural form and space out of fundamental performance using motion capture technology, the research examines how to generate new geometries out of human performance. To achieve the final objective of designing and constructing ubiquitous and comfortable space, the geometries will be evaluated from two different aspects, physical and virtual views. First, captured data are transferred to computer graphics (CG) software to reconstitute them into virtual prototype (VP), and the prototype is evaluated visually and technically using the analysis function of the software. Then it is materialized using rapid physical prototyping (RPP; a 3D printer is used in this research) and further evaluation is carried out using this actual/physical and tactile model from aesthetic and functional viewpoints (Figure 3).

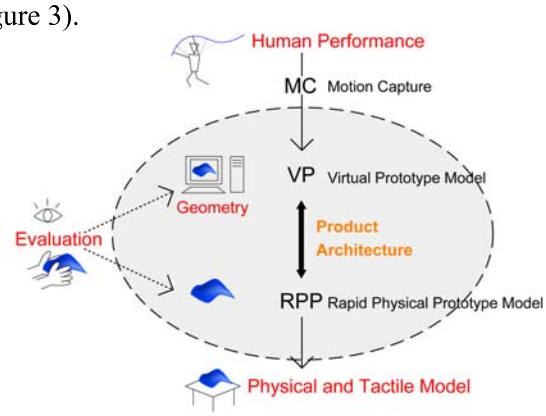


Figure 3. Shape-generating process and evaluation

As for the design process, because the development of the process that incorporates VP and RPP is a key to establishing a methodology to generate a new geometry, their effective combination is to be examined. In the next step, two types of geometries that are generated by human action and by concrete modules such as metric and feet and inches are compared and discussed.

1.4. INTERDISCIPLINARY COLLABORATION

This research is a collaboration with the Department of Information Technology of the author's institution, and it is important to devise this cross-disciplinary collaboration. In principle, Information Technology (IT) people take the lead in terms of the theory and application of motion capture, and the use of motion capture in the architectural discipline is limited to certain areas. For rationalization of logistics and the automobile production line mentioned in the previous sections, research is carried out mostly by the Information Technology group. If they develop applications of motion capture to the architectural field, however, there are limitations due to their limited knowledge about architecture. To facilitate this interdisciplinary research, it is important to establish a methodology that can make the most of the strengths of each department, which starts from sharing knowledge that is common to each party.

2. Unit and formality of architecture

Conventional units of feet and inches in the Western countries, and their Japanese equivalents of *shaku* and *sun*, are based on the human body, and people of these cultures have maintained and developed and the architectural space has been determined by these units. In architectural design, Le Corbusier established a unit system, the Modulor, on the basis of his own theory. He found that the golden section and Fibonacci series are applicable to the human body and compiled a unit system from his findings. He designed various things from small kitchens to large apartments using this human-body-referenced system that is different from conventional units.

However, because one of the objectives of the Modulor is to facilitate standardization and mass production, modern architecture designed for mass use diminished the Modulor's advantage of customizability according to the individual human body. In addition, in light of standardization and mass production it is convenient to apply grid patterns to various aspects of architectural design. Most buildings employ orthographic design, though various architectural designs of complex shape have been experimentally developed. With this logic, corridors are designed functionally straight and we are forced to walk along this straight lane. If we should successfully construct corridors out of the human action of walking, how is the shape of the corridors altered?

3. Experiment

3.1 OBJECTIVES

As the first step in generating form out of the human body and action, the action of walking is captured and tracked as a basis of geometry. Simple walking movement is captured and its trajectories are transformed to surface geometry. Walking is one of the most basic human actions and is thought to be suitable for the first step of this research. Before capturing actual human action, a simulation is carried out as a preliminary experiment using CG software in the same settings as is done with actual motion capture. It is intended to generate geometry not by the conventional concrete units but by the dimensions of the individual human body and her/his performance, and then to apply the methodology to creating architectural space. The process is composed as follows (Figures 4a-4e):

1) Optical markers are put on each joint (indicated by red arrows in Figure 4a).

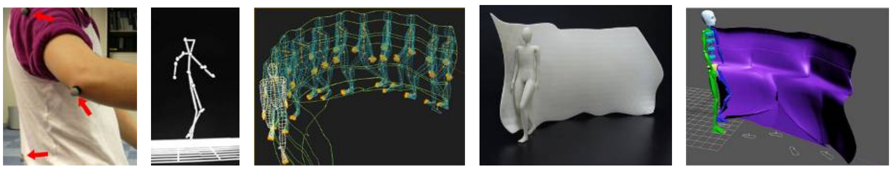
2) The subject walks around inside the detectable area, with the action captured along a timeline.

3) Captured data of action are imported to the “BodyBuilder” analysis software and the data are examined and adjusted (Figure 4b).

4) The data are again transferred to the “3ds max” CG software to connect trajectories of walking action and generate a surface for constructing a virtual prototype (Figure 4c).

5) Out of the same data, a rapid physical prototype is produced to check visual and aesthetic quality (Figure 4d).

6) The surface is also animated along the timeline to simulate how a new geometry might construct space (Figure 4e).

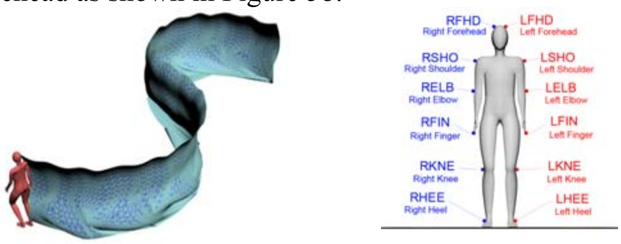


4a 4b 4c 4d
4e

Figure 4a-4e. Process of generating geometry

3.2. RESULT OF SIMULATION

Figure 5a shows a surface that is generated by the CG software simulation out of the trajectories made from S-curved walking by a testee/performer who wore markers on the right side of her body. Optical markers were placed on the right heel, right knee, right finger, right elbow, right shoulder, and right forehead as shown in Figure 5b.



5a 5b

Figure 5a and 5b. Surface generated by the action of S-curved walking

4. Findings

4.1. FORM GENERATED BY WALKING ACTION

As Figures 6 and 7 show, the surface generated by simulation of motion capture of the human action of walking resulted in complex and somewhat disfigured geometry. It proves that even walking, one of the fundamental human actions, can formulate complex shapes out of various motions including rolling of body, swinging of arms, and stepping of feet. Humans, therefore, draw 3D geometry in space accidentally and unconsciously, which indicates the possibility of using motion capture technology as a design tool. Due to differences such as height, weight, and ways of walking, the geometry may differ from person to person. Nonetheless, while it is complex in shape, as long as the width of swinging arms and cycle of stepping are constant some laws of how the surface is constructed can be found. If one did not know that the surface was generated by human walking action, it might seem like something that had been created intentionally.

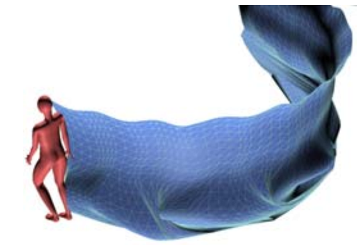
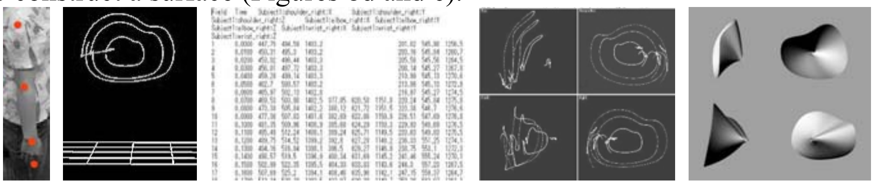


Figure 6. Detail of walker's surface

Figure 7. Physical and tactile RPP model of surface by 3D printer

4.2. FORM GENERATED BY INTENTIONAL ACTION

In the previous section, experimental simulation proved that from human action such as walking, motion capture can generate complex geometry that is different from geometry made by the conventional method, and may be applicable to architectural design. It is, however, necessary to construct not an arbitrary form but a concrete form in case it is necessary to use the form to design products for specific needs. To meet this goal, experiment was carried out using an actual motion capture system, for which a testee/performer wore optical markers on four points of her right arm (shoulder, elbow, wrist, and finger) as seen in Figure 8a and drew an intentional form in the air. Her motion was captured every 0.01 second (Figure 8b). Each trajectory of the marker has coordinates along the timeline (Figure 8c), and the coordinate information was transferred to CG software to construct a surface (Figures 8d and e).



8a 8b 8c
8d 8e

Figure 8a-8e. Generating form with intentional action

With this process it is possible to extract trajectories that humans draw in the air and construct a surface directly out of them, which can liberate the design process from conventional drafting implements and mouse connected to the computer for some parts. It allows prototyping the desired form fairly faithfully, and the effectiveness of the motion capture system as design input tool is verified.

5. Conclusion—new theory of form generation

This preliminary research proves that form can be generated by capturing and tracking trajectories of human action. In architecture, some architects design buildings using their arbitrary interpretation backed by their own long-time experience and insights. While Frank O. Gehry is highly acclaimed thanks to his unique shapes, such arbitrary shapes may lack theoretical background for their forming process and be vulnerable against logical critics. In addition, while arbitrary design can be very original, it is difficult to make compared to design created by concrete logic. In the existing design process, during the course of representing the idea of the form in drawing format and then going on to the production phase, the original idea cannot always be embodied as intended. Contrarily, in the process that adopts motion capture, shapes that may be difficult to design by conventional methods may become possible without losing critical information. In addition, because even people who have no design background can represent their design ideas easily, it may lead to manufacturing customized products according to their body shapes and health conditions, which will contribute to designing not only ordinary products such as furniture but also assistive devices for physically challenged and aging people (Figure 9 for virtual prototype of chair seat).

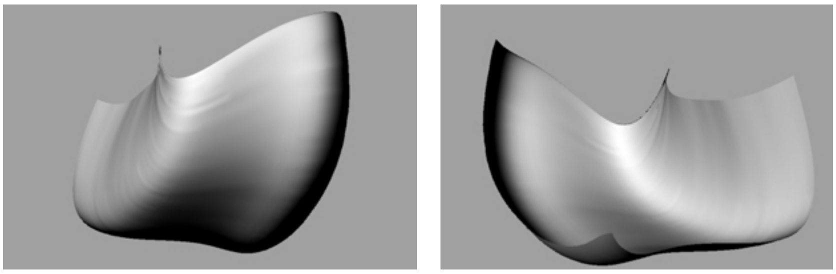


Figure 9. Shape for an easy chair generated from a mother holding her baby

Although this research is in its early stage, once this methodology is established it is expected to become one of the useful methodologies for generating new form and space.

6. Reflection on interdisciplinary collaboration

In this research, collaboration with the Department of Information Technology was essential for the use of motion capture technology, and how to devise this collaborative research should be examined. IT people are good compared to the architecture group in terms of their knowledge and analytical skills related to motion capture, and both parties were able to make the most of their advantages. At the same time there emerged some issues about this collaborative project. For instance, while the architecture group had little knowledge about motion capture technology, the IT group had conducted research on architecture, such as home design by capturing actions that occur inside of the house daily, without knowing Le Corbusier, and it became apparent that neither group had sufficient knowledge to proceed with this research that crosses the border of each discipline. In addition, the terms are defined slightly differently even though both parties speak the same language. As some areas of architectural research and practice that adopt technologies of other disciplines are getting more important, it is critical to devise interdisciplinary collaborations of this kind.

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