

## HUMAN-COMPUTER INTERACTION IN THE FORM-MAKING PROCESS

SALEH KALANTARI<sup>1</sup>, EBRAHIM POUSTINCHI<sup>2</sup> and NOOSHIN AHMADI<sup>3</sup>

<sup>1</sup>*Washington State University, United States of America*

<sup>1</sup>*saleh.kalantari@wsu.edu*

<sup>2</sup>*University of Kentucky, United States of America*

<sup>2</sup>*ebrahim.poustinchi@uky.edu*

<sup>3</sup>*University of Idaho, United States of America*

<sup>3</sup>*nooshin@idaho.edu*

**Abstract.** Many elements of architectural design are becoming automated, and the boundaries between design, construction, and use are increasingly blurred. These developments have produced concerns that our design processes might outrun “human factors” in our search for novelty and automation. At the same time, however, this new technology can also improve our opportunities to develop human-centric environments. This paper describes the creation of an interactive form-making exhibit called ROBOBBLE, and the use of this installation to engage users in design while collecting data about their architectural preferences. The ultimate goal of the ongoing project is to learn more about human form creation and architectural evaluations, and to integrate those findings into computational design algorithms and pre-design toolkits. A pilot study was conducted to test ROBOBBLE as a data-collection platform and to evaluate interactive form-making engagement among a small group of students. The platform was shown to be successful in engaging all of the participants in this pilot study and expanding their creative design capacities over time. Future work using ROBOBBLE for larger population studies has the potential to produce detailed data about a wide variety of design preferences, and to incorporate this data directly into computational design process.

**Keywords.** Human-Computer Interaction; Form-Making; Human Data; Design Process.

### 1. Introduction

The exponential growth of information-processing technology has given rise to an increasing reliance on computational approaches in architecture. These approaches often remove important aspects of the design process from direct human

control. In some cases the entire cycle of form-making, evaluation, and the selection of form alternatives is being carried out computationally. The rapid development of such approaches in architecture raises the concern that the full richness of human experience and evaluation may no longer be present in certain aspects of design, and that a gap may arise between the architect's direct awareness of human needs and the ultimate, computationally-assisted design outcomes.

This study contributes to cutting-edge research efforts in computer-aided design by analyzing the abstract form-making process in the human mind and developing better methods to replicate this process in computational problem-solving. By gaining a better understanding of the current boundaries between designers' visions and computational outcomes, the researchers aim to develop an improved model for incorporating rich human data into the computational design process.

## **2. User-centered Design Cognition**

Architecture is not only a process of creating physical shelter and functionality; it also has a responsibility for promoting psychological and social wellbeing (Leatherbarrow 2009, p. 8). Today we have a wealth of knowledge about human psychological responses to the built environment. Neurobiological approaches to design problems offer a valuable means of understanding both the human response to design and the design process itself. (Sternberg & Wilson 2006). A number of important studies have been conducted from a neurological standpoint to analyze occupant reactions to architectural form (Martínez-Soto et al. 2013; Nanda et al. 2013) as well as the behavior and mental processes of architects as they approach design problems (Cross 2001; Rowe 1991; Schön 1983).

The act of designing a building is intimately connected to the eventual user experience of the design outcome. This insight is not new in the design field; Benedikt (1979) described it as the need "to design environments not by the initial specification of real surfaces but by specification of the desired (potential) experience in space." Béguin (2003) characterized design as a mutual learning process between users and designers. Bannon (1991) emphasized the need to focus on the users of architecture as people in social situations, with specific skills, needs, and shared practices, and to integrate this awareness into technology and design. Schneider and colleagues (2013) described an "inside-out" approach to design that develops the geometry of a building from the user's perspective and based on user needs.

For all of the reasons described above, pre-occupancy evaluation and research into user perspectives is a vital and growing field in architecture, design, and environmental psychology. Design researchers are conducting exciting studies that expand the frontiers of knowledge in this area. Kumar and colleagues (2011) developed an Augmented Reality interface that allowed users to review potential design alterations in healthcare facilities and to provide feedback on these variations. Kalantari (2016) similarly used Augmented Reality to evaluate the relationship between urban architectural forms and human stress responses, incorporating physiological measurements of stress as well as self-reported reactions. Kuliga and colleagues (2015) analyzed user experiences in fully virtual environments to

evaluate redesigns to an existing building layout.

Researchers are also seeking new methods to incorporate user input directly into the design process. Schneider and colleagues (2013) developed a multifaceted approach in which feedback from users as well as from experts in cognitive and environmental psychology is integrated into design studio processes. Jelić and colleagues (2016) drew from phenomenological philosophies to develop what they call an “enactive” approach to design, which is grounded on the understanding of the designer as an embodied organism existing in connection to larger social and natural processes.

The concept of user experience has become foundational in the literature of human-computer interactions and technological product design. In this context, user experience is defined as the highly individual preferences, emotions, motivations, psychological responses, and behaviors that mediate interactions with built objects (Hassenzahl 2010). The investigation into user experience as it relates to technological products has provided a template for many architectural post-occupancy studies, in which user reactions are gathered to evaluate the success of an implemented design. This connection is explicitly noted by a number of post-occupancy researchers (Franz & Wiener 2007; Hölscher et al. 2006; Kuliga et al. 2013). Today’s design technology provides exciting opportunities to integrate these user-experience analyses directly into design methods, so that feedback can be obtained before an architectural edifice is constructed, and even to make end-user input an integral part of the computational design process.

To incorporate user feedback into computational design, it is necessary to analyze the conceptual processes through which human designers and users evaluate a potential form. As noted above, there is exciting work being done in this area using Virtual Reality and Augmented Reality platforms. Today’s technology allows us to go even further, however, in observing how users engage with computer-mediated, flexible design products. Studying user interactions with advanced adaptable designs is a valuable source of information and inspiration for architects who are seeking to develop automated design processes (Krukar et al. 2016).

### **3. Method**

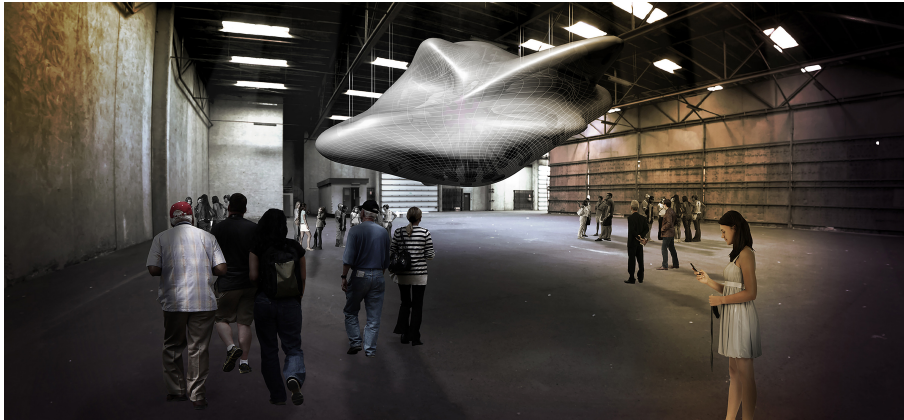
This research is an experiment in data-collection and data-analysis to help develop more responsive computational tools for architects. The purpose is to put the human user at the core of computational form-making. By analyzing user interactions with flexible design products, we lay the groundwork for allowing algorithmic design processes to absorb more inputs in terms of human needs and desires, and then create more responsive, effective outputs on the basis of that data. To accomplish these goals we have developed a flexible physical installation that allows users to experiment with design adaptation through real-time interactions.

#### **3.1. DESIGN**

The installation, named “ROBOBBLE,” incorporates and expands upon earlier work in which designers and researchers attempted to fabricate smart two-

dimensional surfaces that would alter their form to satisfy specific movement-based behavior scenarios (Probst et al. 2011; Raffle et al. 2003). In this case, however, the installation is not limited to a two-dimensional surface or specific design contexts; it is a three-dimensional object that can be continually transformed through user interactions.

ROBOBBLE (shorthand for "Robotic Bobble") was originally conceptualized as an interactive art exhibit; it has now also come to be seen as a valuable means of collecting rigorous and extensive data about user interactions with architectural forms. The installation employs a flexible mesh and tessellated fabrication method. Through the use of a smart-phone app allowing simple push, pull, and soft-transformation commands, users who interact with ROBOBBLE are able to create customized forms in physical space (figures 1, 2 and 3). The sculpture constantly changes based on different audience members' taste and input, blurring the boundaries between designer and users. The cell phone application also allows the researchers to collect detailed data about users' inputs and their responses/adjustments to different design configurations. The aesthetic and playful side of ROBOBBLE belies its serious purpose in demonstrating new ways of bridging the digital and physical worlds and integrating user input into computational design.



*Figure 1. Conceptual rendering of the ROBOBBLE interactive form-making installation.*

### 3.2. FABRICATION

The basic material-technical system of ROBOBBLE consists of spandex fabrics covering a dandelion-like core of linear actuators. The core is a CNC milled plywood twenty four faces, where each face contains an actuator that moves perpendicularly to the face. We tested different types of linear actuator for the project, while considering the requirements of cost, weight, length, and speed, before settling on the existing arrangement. The actuators are powered using transistors in an H-Bridge configuration.

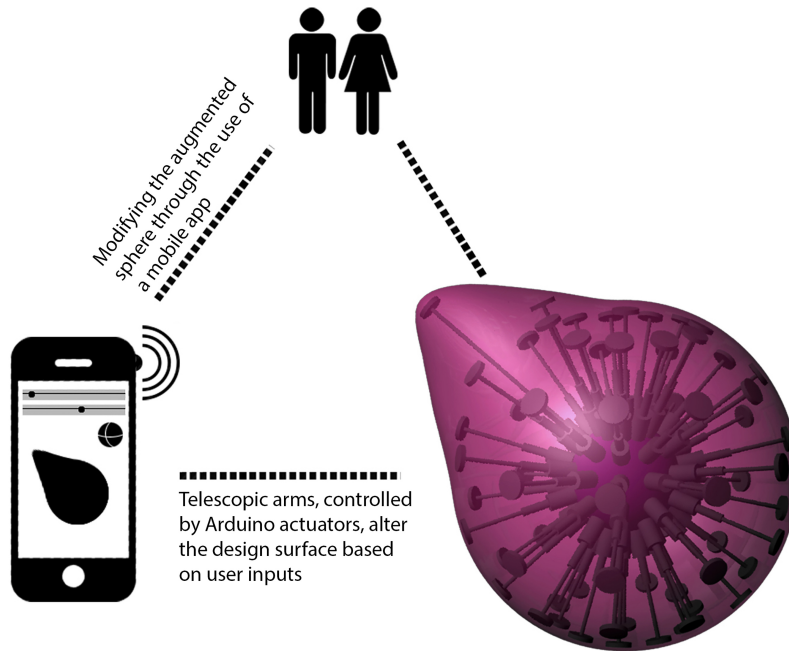


Figure 2. User interaction in the form-making process are carried out through the ROBOBBLE app, designed for smart phones.



Figure 3. Variable forms of ROBOBBLE can be created through the use of 24 linear actuators.

The Arduino Mega kits and servos that control the actuators are located inside the plywood core and receive instructions from a design-oriented cell phone application using Bluetooth technology. The end-arms of the actuators (made out of Styrofoam) create soft connections with the surrounding spandex fabric shell. The shell itself has the capacity to expand up to 2.5 times its resting size, which allows the overall geometry of the sculpture to take on a variety of forms and scales (figure 4 and 5).

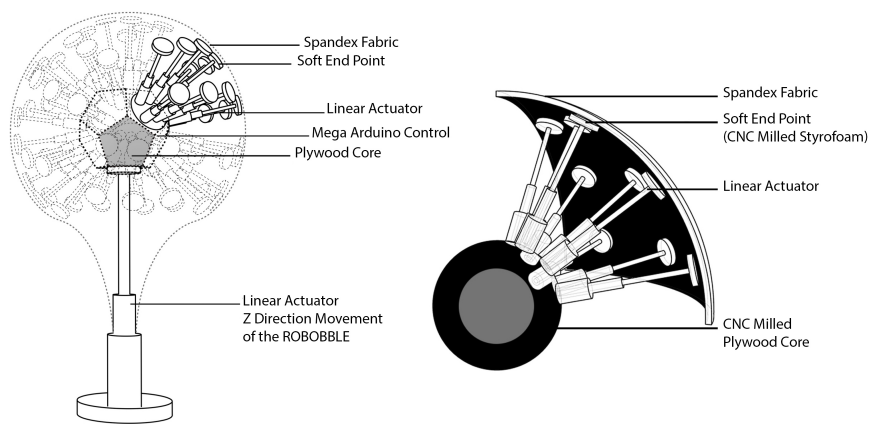


Figure 4. Detail of the ROBOBBLE core, the connection of the linear actuators to the core, and the connection of structure to ground.

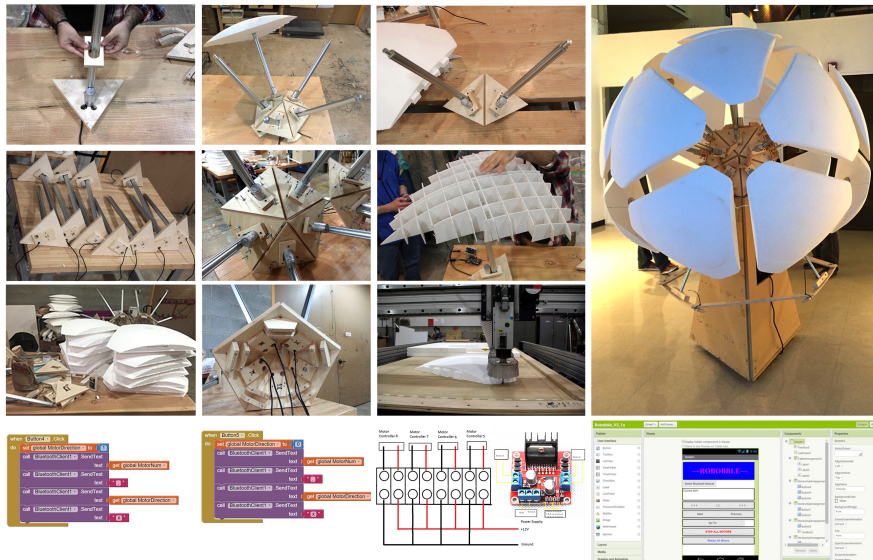


Figure 5. ROBOBBLE fabrication process.

### 3.3. INTERACTION AND EVALUATION

The users who interact with ROBOBBLE must first provide informed consent, download the project app to their smart phones, and answer a few demographic questions. They are then introduced to the simple and user-friendly tools that will allow them to adjust the installation's form. As they engage with the design, their inputs and responses are anonymously collected for analysis. The goal of the data collection and analysis is to evaluate the users' perceptions of form and the manner in which they go about producing a form that fits their needs and goals.

This paper reports the results of a pilot study that was conducted to test the use of ROBOBBLE in collecting data about design inputs. The purpose of this pilot study was to collect exploratory/qualitative data that can later be investigated in a more rigorous fashion. Ten undergraduate students participated in this pilot study, including five who were majoring in design fields and five who were in non-design majors. Each student interacted with ROBOBBLE separately, using the cell-phone app to generate a unique form. The installation was set to a simple sphere (null position) before each participant entered the exhibition room, and each participant was given a total of 20 minutes to create their design. The other participants were then asked to analyze, rank, and discuss each design. We repeated this process three times, allowing the students to learn from the previous round and experiment with new ideas (thus, 30 designs total). At the end of the study we held a focus group discussion with the participants, encouraging each of them explain their experiences and talk about the forms that they generated.

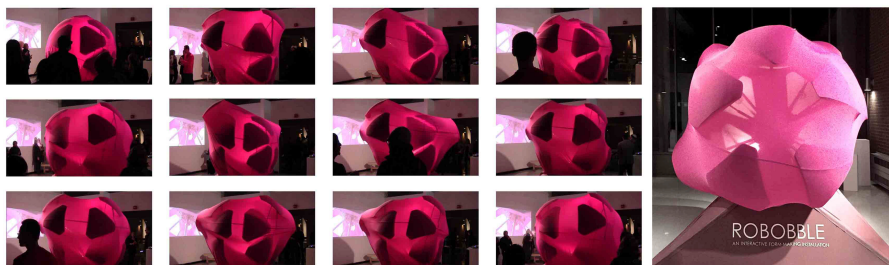


Figure 6. An early prototype of ROBOBBLE at Washington State University Fine Art Gallery.

## 4. Results and Discussion

During the first round of student designs (10 forms), we observed significant differences in outcome between the students with design backgrounds and those who lacked such background. The forms generated by design students were ranked higher by all participants and tended to be explained with words such as “creative,” “meaningful,” and “art.” In the first round of peer evaluations, the five forms created by design students were ranked as the top five, while those created by other students were ranked as the bottom five. However, this division did not hold in the second and third rounds of form generation, during which the non-design students gained ground and in some cases created forms that surpassed the peer rankings

given to the products of the design students. This result seems to affirm a great potential for interactive design as a learning mechanism.

During the focus group, all ten of the students agreed that they learned from their peers' designs during the course of the study, and most of them regarded the process as being entertaining and engaging. Some of the students even asked if they could continue for additional rounds in order to try out new ideas. The majority (8 out of 10) stated that during the second and third round of form generation they had sought to create more semantic designs that would convey a particular meaning. The students agreed that these later rounds produced more creative and superior results. More concrete data gathered during the study supports this evaluation, indicating more complex and careful geometries. The number of actuators engaged during the first-round designs averaged 9.45 (out of 24). In the second round this number rose to 11.76, and in the third round it rose again to 14.43.

From the limited basis of this initial pilot study, it seems that experimentation with interactive physical form-making using ROBOBBLE led to meaningful learning experiences and engaging opportunities for creativity. The ongoing work in this project will give us ample opportunities to gather data on human preferences during the form-generation process. Ultimately our goal is to assess the types of learning and experimentation that lead toward better-received design outcomes, and to incorporate this knowledge into algorithmic processes and pre-occupancy design evaluation toolsets.

## 5. Conclusion

The design, fabrication, and implementation of ROBOBBLE involved a forward-looking collaboration of researchers from the architecture, psychology, and robotic-engineering fields, incorporating diverse technologies into a seamless product. Bringing these different sets of technologies together in design and fabrication reflects the future of the form-generation process, which will increasingly integrate active human behavior with form design. The use of real-time, linked digital and physical form-making expands the boundaries of the architectural medium, and has the potential to be a transformative tool in the hands of designers and artists. The results from this ongoing study allow us to better understand preferences and processes in attaining design solutions, and to more fully integrate those human preferences into computational design algorithms. By expanding the boundaries of human-computer interaction in design, we can gradually merge formal studies in digital space with hands-on conceptualization in the physical world, thereby heightening the qualities and possibilities of both approaches. A wide range of implementations of this research are possible, from programs that simply assist designers in collecting data and exploring the possibilities of form, to fully automating greater portions of the design process with more effective results.

## 6. Limitations and Future Work

The results reported in this paper are for a pilot study, and cannot be generalized to larger populations. Our project is still in its initial phases and we are excited about the multitude of possibilities in design research that the use of the ROBOBBLE



system will enable. In the next phase of the research, users will engage in a hybrid digital/physical experience that includes a parametric modeling platform, which is a significant expansion of our initial phone app and will allow for more detailed design explorations through a specifically designed input device. This development will increase our capacity to collect precise data about design processes and form-making preferences.

Future work may also see new developments in the physical ROBOBBLE system. One notable point of feedback that we gained from our pilot study participants is that they often felt a desire to “look inside” the ROBOBBLE structure, so that they could see the result of their designs in terms of interior spaces. This is not possible in the installation’s current configuration, but it may be addressed in the future by expanding the size of ROBOBBLE and adding viewports. The current form of the installation is also somewhat limited by the flexibility range of the exterior mesh and the need to fix the structure to a stand (rather than hanging it from the ceiling). These limitations may be addressed in the future project development, allowing even more possibilities for users to experiment with form.

## References

- Bannon, L.: 1991, From human factors to human actors: The role of psychology and human-computer interaction studies in system design, *Design at Work: Cooperative Design of Computer Systems*, **25**, 44.
- Benedikt, M.L.: 1979, To take hold of space: Isovists and isovist fields, *Environment and Planning B: Planning and Design*, **6**(1), 47–65.
- Béguin, P.: 2003, Design as a mutual learning process between users and designers, *Interacting with Computers*, **15**(5), 709–730.
- Cross, N.: 2001, Designerly ways of knowing: Design discipline versus design science, *Design Issues*, **17**, 49–55.
- Franz, G. and Wiener, J.M.: 2007, From space syntax to space semantics: A behaviorally and perceptually oriented methodology for the efficient description of the geometry and topology of environments, *Environment and Planning B: Planning and Design*, **34**(4), 574–592.
- Hassenzahl, M.: 2010, Experience design: Technology for all the right reasons, *Synthesis Lectures on Human-Centered Informatics*, **3**(1), 1–95.
- Hemmerling, M.: 2008, Digital material: Perception, interaction, and immersion in virtual environments, *Proceeding of 9th Design & Decision Support Systems in Architecture and Urban Planning*, Eindhoven, Netherlands.
- Hölscher, C., Meilinger, T., Vrachliotis, G., Brösamle, M. and Knauff, M.: 2006, Up the down staircase: Wayfinding strategies in multi-level buildings, *Journal of Environmental Psychology*, **26**(4), 284–299.
- Jelić, A., Tieri, G., De Matteis, F., Babiloni, F. and Vecchiato, G.: 2016, The enactive approach to architectural experience: A neurophysiological perspective on embodiment, motivation, and affordances, *Frontiers in Psychology*, **7**, 1–20.
- Kalantari, S.: 2016, A digital pre-occupancy architectural toolset for reducing stress levels in urban environments, *GSTF Journal of Engineering Technology*, **4**(1), 8–12.
- Krukar, J., Dalton, R.C. and Hölscher, C.: 2016, Applying HCI methods and concepts to architectural design (or why architects could use HCI even if they don’t know it), *Proceeding of Architecture and Interaction*, New York, 17–35.
- Kuliga, S.F., Thrash, T., Dalton, R.C. and Hölscher, C.: 2015, Virtual reality as an empirical research tool: Exploring user experience in a real building and a corresponding virtual model, *Computers, Environment and Urban Systems*, **54**, 363–375.
- Kumar, S., Hederick, M., Wiacek, C. and Messner, J.: 2011, Developing an experienced-based

- design review application for healthcare facilities using a 3d game engine, *Journal of Information Technology in Construction*, **16**, 85–104.
- Leatherbarrow, D.: 2009, *Architecture oriented otherwise*, Princeton Architectural Press, New York.
- Lifton, J., Broxton, M. and Paradiso, J.A.: 2003, Distributed sensor networks as sensate skin, *Sensors: Proceedings of IEEE*, New York, 743–747.
- Martínez-Soto, J., Gonzales-Santos, L., Pasaye, E. and Barrios, F.A.: 2013, Exploration of neural correlates of restorative environment exposure through functional magnetic resonance, *Intelligent Buildings International*, **5**, 10-28.
- Nanda, U., Pati, D., Ghamari, H. and Bajema, R.: 2013, Lessons from neuroscience: Form follows function; emotions follow form, *Intelligent Buildings International*, **5**, 61–78.
- Neutra, R.: 1954, *Survival through design*, Oxford University Press, New York.
- Probst, K., Seifried, T., Haller, M., Yasu, K., Sugimoto, M. and Inami, M.: 2011, Move-it: Interactive sticky notes actuated by shape memory alloys, *Proceeding of Ext. Abstract CHI '11, ACM*, 1393–1398.
- Raffle, H., Joachim, M.W. and Tichenor, J.: 2003, Super cilia skin: An interactive membrane, *Proceedings of the conference on computer human interaction*, Lauderdale, FL, 808–809.
- Rowe, P.G.: 1991, *Design thinking*, MIT Press, Cambridge.
- Schneider, S., Kuliga, S., Hölscher, C., Dalton, R.C., Kunert, A., Kulik, A. and Donath, D.: 2013, Educating architecture students to design buildings from the inside out: Experiences from a research-based design studio, *Proceedings of the 9th International Space Syntax Symposium*, Seoul, South-Korea.
- Schön, D.A.: 1988, Designing: Rules, types, and words, *Design studies*, **9**(3), 181–190.
- Sternberg, E.M. and Wilson, M.A.: 2006, Neuroscience and architecture: Seeking common ground, *Cell*, **127**(2), 239–242.