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CONVENTIONS OF CONTROL:

A CATALOG OF GESTURES FOR REMOTELY INTERACTING WITH DYNAMIC ARCHITECTURAL SPACE

ABSTRACT

The intent of this project is to create a catalog of gestures for remotely controlling dynamic architectural space. This research takes an essential first step toward facilitating the field of architecture in playing a role in developing an agenda for control. The process of the project includes a sequence carried out in four stages: 1) research of gestural control; 2) creating an initial catalog of spatial architectural gestures; 3) real-world testing and evaluation; and 4) refining the spatial architectural gestures. In creating a vocabulary for controlling dynamic architectural environments, the research builds upon the current state-of-the-art of gestural control, which exists in integrated touch- and gesture-based languages of mobile and media interfaces. The next step was to outline architecturally specific dynamic situational activities as a means to explicitly understand the potential to build gestural control into systems that make up architectural space. A proposed vocabulary was then built upon the cross-referenced validity of existing intuitive gestural languages as applied to architectural situations. The proposed gestural vocabulary was then tested against user-generated gestures in the following areas: frequency of "invention," learnability, memorability, performability, efficiency, and opportunity for error. The means of testing was carried out through a test-cell environment with numerous kinetic architectural elements and a Microsoft Kinect sensor to track gestures of the test subjects. We conclude that the manipulation of physical building components and physical space itself is more suited to gestural physical manipulation by its users than to control via device, speech, cognition, or other. In the future it will be possible, if not commonplace, to embed architecture with interfaces to allow users to interact with their environments, and we believe that gestural language is the most powerful means of control because it enables real physical interactions.

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1 MOTIVATIONS

The motivation for this research is to serve as somewhat of an "intervention" to the current profusion of exploration in robotic and interactive architecture, in terms of application design and prototyping as well as full-scale exhibits. As architectural scenarios move beyond direct sensing and response conditions, we are confronted by the need for more natural and direct means of control. Many in the architectural profession have begun to study and learn from interactive media precedents and usurp the technologies employed for controlling interactive digital environments. Currently, the field of architecture is adopting control strategies that may or may not be applicable to larger-scale architectural applications. While a building or facade or environment may be an interface, it is not a device. Furthermore, while a two-year-old may be able to open an application on a phone, what strategy would he use to open a skylight window in a house? The gestural language for architectural control simply has not been developed.

While this paper uses technology as a means to explore the problem via a test-cell with a hacked Microsoft Kinect sensor, it is important to state up front that this paper is by no means about the technology used as a means to explore the problem of a lack of gestural vocabulary. We are not the first to use this technology, and we optimistically hypothesize that in a few years many in the architectural profession will be exploring the potential of gestural control. This research could in fact be carried out by any number of technological strategies used to test gestures at an architectural scale. The motivation of "intervention" is rather to establish a framework for future explorations, which consequently forced us to confront a number of questions surrounding gestural control in architecture, including: 1) what specifically the profession of architecture should usurp and modify in terms of gestural vocabularies already used for interaction; 2) why the profession would need a vocabulary; and 3) why the profession should even pursue gestural control as opposed to remote device control, speech recognition, cognitive or other control.

2 THE STATE OF THE ART

Initially, the research builds upon the current state-of-the-art of gestural control, which exists in integrated touch- and gesture-based languages of mobile and media interfaces. Much of the software being developed in interface design is centered on managing vast amounts of information, while little has been explored in terms of controlling objects in space. Technologies that allow users new means to control and interact with digital information can be broken down into three general categories: touch and multitouch, gesture, and cognitive control. To date, there are many touch and multitouch interfaces; gesture interfaces are still in their infancy with regard to architectural applications; and direct cognitive controls reside on the developmental horizon but show fascinating promise.

2.1 Previous Research

The research used as a launching point for this project consists mostly of studies in three categories: (1) experiments in scale and accuracy of gestural recognition using a hacked Microsoft Kinect; (2) the automated creation of gestural libraries and consequent categorization of gestures; and (3) testing of various gestural languages among user groups to evaluate learnability and overall success rate of the vocabulary.

2.2 Emergence of Ubiquitous Gesture-Controlled Technology

The growing emphasis on using space to organize information in current interface design will begin to evolve into interfaces that are more integrated with their immediate surroundings. New technologies, specifically tied to touch-based, gesture-based, and cognitive control, are beginning to see increased use in mobile devices, online interfaces, video game consoles, and environmental displays. New relationships are emerging between interfaces and users as we see the increased integration of user control and information through a new digital-physical space. Users are beginning to be able to directly manipulate and interact with complex data and media through gesture and touch. These technologies, which are beginning to adopt standards and user experience guidelines, are creating unprecedented possibilities for the way we can interact with information.

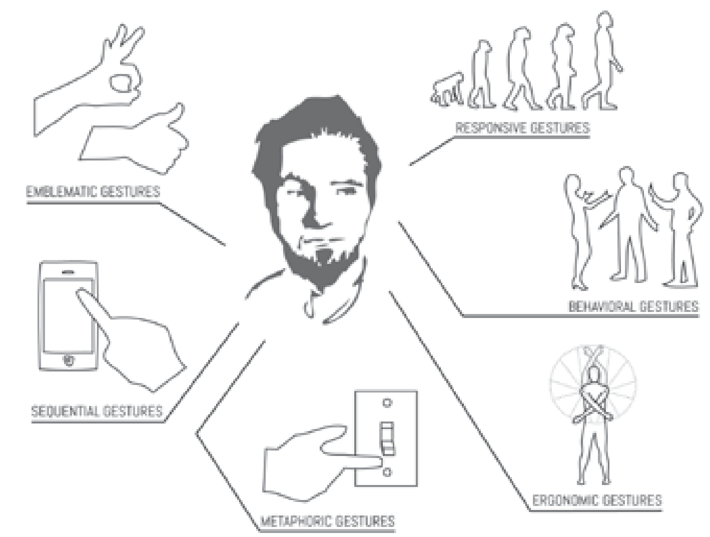

figure 1

figure 2

2.3 Relative Gestural Intuition

Intuitive gestures are built from several gestural languages that we already know. Throughout the project, gestures are always categorized according to six origins of intuition (Figure 1).

Responsive gestures respond to one's surroundings or environment. Examples of responsive gestures include squinting of the eyes when trying to see something in the distance, shading the eyes in the glare of the sun, or shivering when cold. Ergonomics influence all gestures because a gesture that does not correspond to the body's natural movements and range of motion is difficult to perform, and therefore will eventually become overwritten by a more comfortable gesture. Emblematic gestures represent words and figures of speech. Behavioral gestures are used to convey emotion when communicating with other people. Sequential gestures to control new technology refer to gestural languages of the most recent existing technology. For example, dragging and dropping a file into a folder using a mouse on a computer imitates the previous version of file/folder technology. Before the digital era, data storage consisted of physical files literally dropped into physical folders in a filing cabinet. Following this sequence, many touchscreen mobile devices use a drag gesture for the most basic commands. Finally, metaphoric gestures reference motions related to physical objects in the real world, often with no association to their modern digital adaptations (Figure 2).

An example of a metaphoric gesture is shaking a mobile phone in order to exit running applications and return to the home screen (Figure 3). In the physical world, we shake a carton of juice, a bag of popcorn, or even another person to return the object to a stable or restored state that is ready for the next task.

2.4 Precedents: Mobile and Media Interfaces

We are beginning to understand how people can control their environments through integrated touch- and gesture-based languages with software and hardware that were developed for mobile and media projects (Figure 4).

Some of the current themes continue to be based on a desire to create user-friendly, customizable,

figure 1
Origins of intuitive gestural languages.

figure 2
Reference motion.

figure 3
NTT DoCoMo D904i motion sensor technology.

figure 4
Android mobile phone gestural interface.

figure 5
Sixth Sense wearable gestural interface.

figure 6
Common gesturecons.

figure 3

and immersive interactive experiences for users (Figure 5).

Many mobile and media interface gestures have already been cataloged according to which actions they perform. Gesturecons can now be seen in product user guides and instruction manuals as visual cues to teach users how to execute certain commands (Figure 6).

The following matrix categorizes existing gestures and shows which types of intuitive languages they originated from (Figure 7). Current precedents in interface design are very useful in understanding how relationships are being developed between information in interfaces and users controlling or interacting with these interfaces. Manipulations of the physical world have the most influence on gestural vocabularies, as shown by the large occurrence of metaphoric gestures in the matrix.

figure 4

figure 5

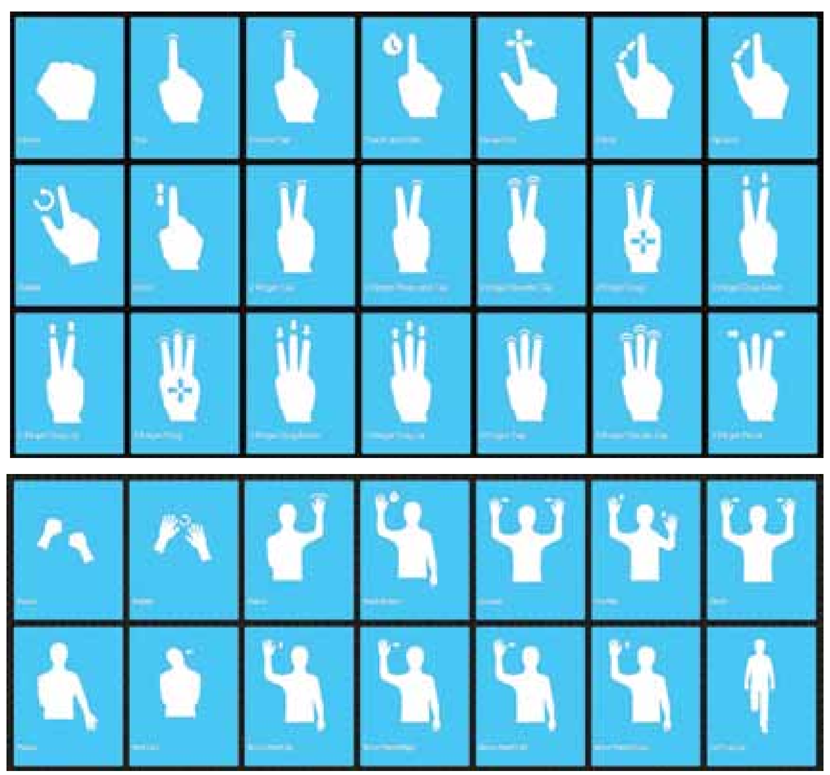

figure 6

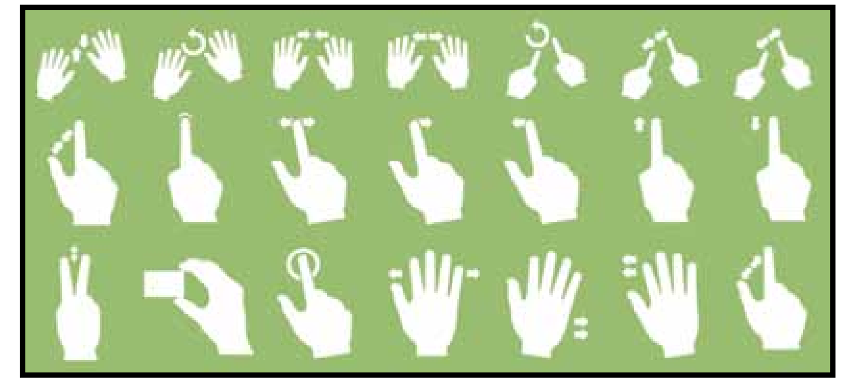

figure 6 continued

3 WHAT TO USURP, WHAT TO LEAVE BEHIND

3.1 General

The project hypothesis is that when interacting with physical instead of digital objects in an interactive space, users will even more overwhelmingly prefer metaphoric gestures. However, metaphoric gestures may not be appropriate in an architectural setting because of the lack of abstraction of reality in a physically interactive space. Though sequential gestures (based on existing touch-interface languages) will be popular among the user-generated gestures, they will be ineffective due to the absence of a physical input device. Users will prefer nonmetaphoric or responsive gestures that allow additional levels of interaction with the space. Finally, the project considers the possibility of preference for nonintuitive gestures that exhibit extreme physical movements as a response to the removal of a constraining physical interface device.

3.2 User Dependence on Knowledge of Component Assembly

Using literal metaphoric gestures to interact with architectural components such as doors or windows would require a high level of gesture customization to match the physical acts of manipulating those objects, which are designed in many different ways. Doors can have hinges on any one of 12 edges. They can swing, pivot, slide, roll, or fold open or closed. Using a literal metaphoric vocabulary might mean creating a different gesture to manipulate each door configuration.

If users do not have a certain level of technical knowledge, they might not be able to understand how a component physically works, and thus will not be able to operate it even with a simple gesture. Besides, gestural control is meant to enhance an interactive environment, not burden its users. The ultimate purpose of a gesture is to send a signal. Whether this signal is to open, close, or rotate, it is up to the programming of the computer in the background and the mechanics of the architecture to complete the given task—not the user.

3.3 Nondirectional Metaphoric Gestures

Even abstract metaphoric gestures are frequently directional and can thus be confusing. A flick to the left to always close any door does not make sense when the door closes in the opposite direction once you are on the other side of it. It is best to use nondirectional metaphoric gestures in the manipulation of interactive architecture to eliminate confusion among users who encounter various types of the same building component each day. An example of a nondirectional metaphoric gesture is: from a fist, pop up the pointer finger into the "number one" sign. This is metaphoric in that it represents an object popping open, like a jack-in-the-box. Since it is nondirectional and

GESTURE-BASED MANIPULATION: THE STATE OF THE ART — DESCRIPTION OF GESTURES

CATEGORY: SYSTEM, APPLICATION, NAVIGATION. COMMAND: COMMON NAME. INTERFACE: X = DEFINED GESTURE OF THE RESPECTIVE INTERFACE LANGUAGE (MOBILE, MEDIA, APPLICABLE TO ARCHITECTURE). NAME: SEE ILLUSTRATION MATRIX FOR GRAPHIC DESCRIPTION (MATRIX ID #). DEGREE: STATIC POSTURE, DYNAMIC MOTION, SPATIO-TEMPORAL, # DISTINCT MOVEMENTS. MEANS: FINGER (F), HAND (H), ARM (A); # = AMOUNT NEEDED. METHOD: (2D) = SURFACE-BASED, (3D) = DEVICE-BASED, (M) = FREE MOTION. REFERENCE: REFERENCE POINT NEEDED? X = YES. INTUITION IS RELATIVE: EMBLEMATIC = REPRESENTING WORDS/SYMBOLS; METAPHORIC = REPRESENTING INTERACTION WITH PHYSICAL OBJECTS; SEQUENTIAL = REPRESENTING A PREVIOUSLY LEARNED FORM OF GESTURAL LANGUAGE; BEHAVIORAL = REPRESENTING TRADITIONAL HUMAN-TO-HUMAN GESTURING; RESPONSIVE = AN UNCONSCIOUS ENVIRONMENTAL RESPONSE.

CATEGORY	COMMAND	INTERFACE			NAME		DEGREE				MEANS				METHOD			REFERENCE	INTUITION IS RELATIVE				
		M	E	A	NAME	#	S	D	T	#	F	H	A	#	2D	3D	M	Y	E	M	S	B	R
SYSTEM	POWER UP	M			TAP+HOLD	#		D	T	1	F			1		3D				M			
	HOME	M			PINCH	#		D		2	F			3+	2D						S		
		M			SHAKE	#		D		2		H		1		3D				M		B	
			E	A	TOUCHDOWN	#	S			1			A	2			M					B	
	ACTIVATE	M			DRAG	#		D		2	F			1	2D					M			
			E	A	PIVOT UP	#		D		2			A	1, 2			M			M			
	POWER OFF	M			TAP+HOLD	#		D	T	1	F			1		3D				M			
APPLICATION	SELECT	M			TAP	#		D		1	F			1	2D			Y		M	S	B	
			E	A	CLASP	#	S	D		2		H		1			M			M		B	
			E	A	POINT	#	S			1		H		1			M	Y				B	
			E		PUSH	#		D		2			A	1			M	Y		M	S	B	
	OPTION	M			TAP+HOLD	#		D	T	1	F			1	2D					M	S		
		M			DOUBLE TAP	#		D		2	F			1	2D						S	B	
		M			TAP+HOLD+TAP	#		D	T	2	F			2	2D						S		
			E	A	PUSH AND HOLD	#		D	T	2			A	1			M			M			
			E		HOVER	#	S		T	1			A	1			M				S		
	ACTIVATE	M			TAP+HOLD	#		D	T	1	F			1	2D					M	S		
		M		A	DOUBLE TAP	#		D		2	F			1	2D						S	B	
			E		"A-OK"	#	S			1		H		1			M		E			B	
			E	A	PUSH AND HOLD	#		D	T	2			A	1			M			M			
			E		SPREAD	#		D		2			A	2			M	Y		M			
	PAUSE	M			TAP	#		D		1	F			1	2D					M	S	B	
			E		"HALT" (SHOW PALM)	#	S			1		H		1			M		E			B	R
	EXIT / BACK	M			TAP	#		D		1	F			1	2D			Y			S		
		M			FLIP, TURN OVER	#		D		1				1		3D				M			
			E		REPEATED WAVE	#		D		2		H		1			M		E			B	
			E		PIVOT DOWN	#		D		2			A	1, 2			M			M			
			E		TOUCHDOWN	#	S			1			A	2			M					B	
			E		SHOVE	#		D		2			A	2			M			M		B	
	LISTEN	M			HOLD TO EAR	#		D	T	1			A	1		3D		Y	E	M	S	B	R
	SILENCE	M			REMOVE FROM EAR	#		D	T	1			A	1		3D		Y		M	S		R
		M			FLIP, TURN OVER	#		D		1		H		1		3D				M			
		M			SQUEEZE	#		D		1		H		1		3D						B	
	TRANSFER		E		BUMP	#		D		1		H		1		3D		Y		M		B	
			E		HOVER (DROP)	#	S		T	1		H		1		3D		Y		M	S		
NAVIGATION	PAN	M			DRAG	#		D		2	F			1	2D					M	S		
		M			TILT	#		D		1		H		1		3D					S		
			E		SWEEP	#		D		2			A	1			M			M	S		
	SCROLL	M			FLICK	#		D		1	F			1	2D					M	S	B	
			E	A	SWIPE	#		D		1			A	1			M				S	B	
	PAUSE	M			TAP	#		D		1	F			1	2D					M	S	B	
			E	A	"HALT" (SHOW PALM)	#	S			1		H		1			M		E			B	R
	SWITCH	M		A	FLICK	#		D		1	F			2+	2D					M		B	
			E		SHUFFLE	#		D		2+			A	2			M	Y		M			
			E		ASSOCIATIVE SPREAD	#		D		2+			A	2			M	Y	E	M			
	MOVE	M			DRAG	#		D		2	F			1	2D					M	S		
			E	A	SWEEP	#		D		2			A	1			M			M			
	ADJUST	M			DRAG	#		D		2	F			1	2D					M	S		
			E	A	PIVOT	#		D		2		H		1			M			M			
			E	A	SWEEP	#		D		2			A	1			M			M			
			E		SHUFFLE	#		D		2+			A	2			M	Y		M			
	ZOOM IN	M			PINCH	#		D		2	F			2	2D			Y			S		
			E		SPREAD	#		D		2			A	2			M	Y			S		
			E		ASSOCIATIVE SPREAD	#		D		2+			A	2			M	Y					
			E		MOVE TOWARD EYES	#		D		2			A	2			M	Y		M			R
	ZOOM OUT	M			JOIN FINGERS	#		D		2	F			2	2D			Y	E		S		
			E		JOIN HANDS	#		D		2			A	2			M	Y			S		
			E		ASSOCIATIVE CONVERGE	#		D		2+			A	2			M	Y					
			E		MOVE FROM EYES	#		D		2			A	2			M	Y					R
	ROTATE	M			ROTATE	#		D		2+	F			2	2D					M	S		
		M			ORIENT	#		D		1		H		1		3D				M			
			E		SPIRAL	#		D		2+			A	2			M				S		
			E	A	DRAW CIRCLE	#		D		2+			A	1			M		E		S	B	

figure 7

not hardware specific, it can be used as a universal gesture to open any type of window or door. Nondirectional metaphoric gestures form the basis of the proposed vocabulary to control dynamic architectural space (Figure 8).

3.4 Proposed Architectural Gestures

The architectural matrix lists the proposed gestures for interactive architecture applications (Figure 9). These include: system activation/sleep, "home" to exit out of a command, selection gestures, "option" command applicable to augmented reality applications, generic open/close, generic adjustable open/close, generic 3D rotate, and more specific responsive commands (environmentally intuitive).

4 TESTING PHASE

In addition to recording user-generated gestures, the proposed gestures will be researched in the test cell by teaching subjects the suggested language, then testing their ability to successfully perform the gesture and receive the intended reaction from several components.

In addition to defining a catalog of architectural gestures, the research is intended to further define the notion of "intuition" in relation to the creation of gestural languages. The project wishes to discover the most referenced categories of relative intuition among test subjects prompted to "invent" gestures for specific architectural tasks. In pursuit of defining a suggested catalog of gestures for manipulating interactive space, proposed gestures will be tested against user-generated gestures in the following areas: frequency of invention, learnability, memorability, performability, efficiency, and opportunity for error.

4.1 Test Cell Description

This project employs the use of a built prototype as a means to evaluate the gestures relative to architectural scale. As a means to explicitly understand gestural control relative to the physical architectural environment, a simple full-scale mock-up of a 8' × 12' space consisting of three walls and no ceiling is constructed to test gestures and kinetic motion (Figure 10). A hacked version of

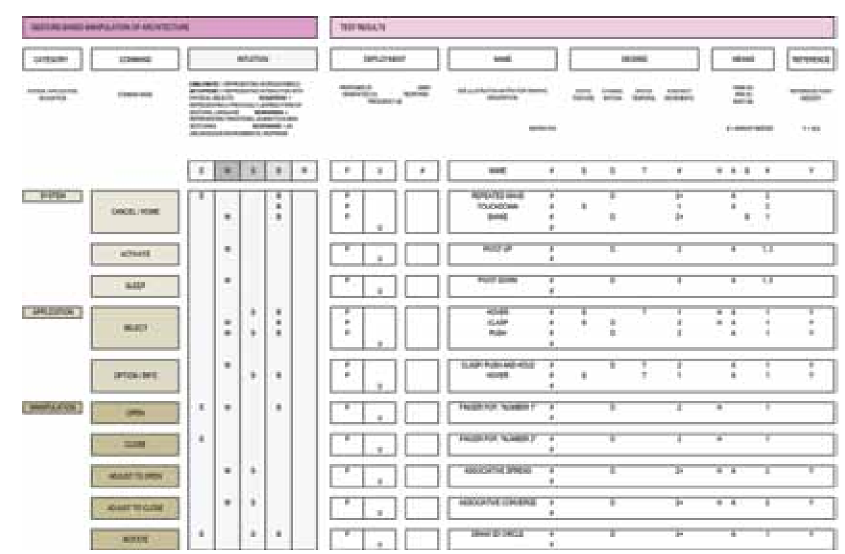

figure 9

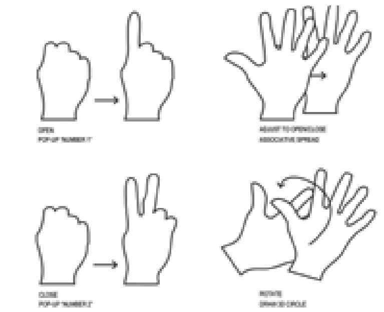

figure 8

figure 7
State-of-the-art matrix.

figure 8
Proposed metaphoric gestures.

figure 9
Matrix of proposed vocabulary.

a Microsoft Kinect sensor is adapted to recognize specific gestures that will control several servo motors in the prototype to operate several types of windows, open and close a door, and control a sliding wall partition, among other scenarios. Within the wall are placed three motorized windows and a door that can each be controlled individually and that rotate or slide in different axes or directions.

The initial prototype is conceived to facilitate additional functionality both in terms of the kinetic disposition and the gestural capabilities that may include multi-hand and body movements with respect to adaptable architectural scenarios. The intent of this proposal is to design and evaluate the prototype as a strategic project aimed at understanding gestures that are useful to control motion in the physical environment. A further goal is to understand dynamic situational activities and explicitly understand the potential to build gestural control into systems that make up architectural space.

The tectonic objectives of the physical prototype are intentionally simple so that it can easily be further developed and applied to more complex architectural components or scenarios. The prototype explores the functionality of gesture recognition technology related to architecture in small to medium scales, as in a residential or commercial setting. Since physical interaction is being simulated, the metaphoric connection will be lost if the user performs the gestures too far away from the component to be controlled.

In the context of the test cell, subjects are asked to control the various architectural components via gestures alone (Figure 11). Movements and body positioning are recorded and categorized, creating a taxonomy of user-generated "intuitive" gestures. Analysis reveals that intuitive gestures come from several different gestural languages that we already know. Transposing the user-generated gestures with a suggested gestural vocabulary based on technological precedents defines the product of this research: a catalog of intuitive gestures for remotely controlling dynamic space.

Common gestures will be documented, the software will be revised so that they become standardized, and the test will be run again. A catalog of successful gestures will then be documented according to the specific tasks. A summary of architectural scenarios for which the gestures may be applicable will also be documented.

In terms of simple gesture recognition, the Microsoft Kinect sensor will be used to track gestures of the test subjects. The sensor is an appropriate means of control that can serve to mimic actions

figure 10

figure 10

Constructed test cell.

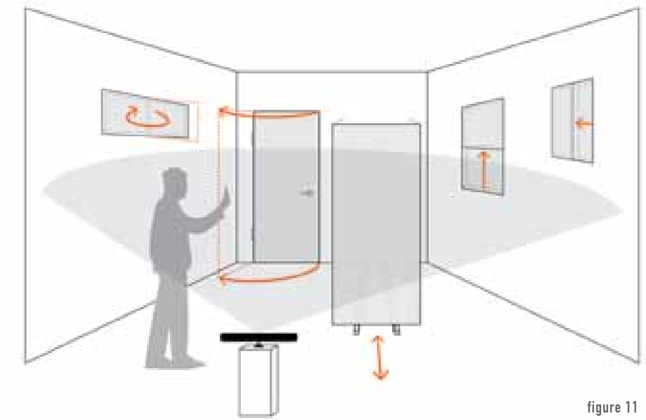

figure 11

figure 11

Test cell diagram.

in the real world, as opposed to pressing buttons. In addressing the performance parameters of the prototype, the concept will focus on several key strategies: 1) gestures, 2) physical movement, and 3) scale. A full list of operations will be fully explored in the first phase of this project but will be limited to the prototype space that contains three windows, a standard hinged door, and a sliding door. Specific goals will be defined, including 1) individual device selection, 2) full or partial operation, and 3) opening or closing. Speed of motion will not be considered.

The final objective of the approach is to create an innovative design that is minimally functional, with the capability for evolving additional multifunctionality. Future applications may include motorized roller shades and/or a table that can slide out from the wall.

5 CONCLUSIONS

Interactive architectural environments and the gestural vocabulary they will require are an essential element in the transformation from interactive media interfaces to complete augmented or virtual reality (Figure 12). The manipulation of physical building components and physical space itself is more suited to physical manipulation by users than control via speech or device. In the path toward a more virtual or automated reality, we must not lose the ability to physically interact with our surroundings.

In the future it will be possible, if not commonplace, to embed architecture with interfaces that allow users to interact with their environments, and we believe that gestural language is the most powerful means of control through enabling real physical interactions. Advancements in multitouch hardware technology are significant to architecture because in many cases the gestures used to control an interface are the most similar to gestures that would be used to replicate these activities in real space with tangible objects.

This research points out the importance of body-space relationships with respect to our architectural environments. We conclude that the manipulation of physical building components and physical space itself is more suited to gestural physical manipulation by its users than control via device, speech, cognition, or other. Gestural control is applicable to the following architectural systems: partition walls, skylights, doors, windows, lighting, and temperature. Responsive gestures as an input can easily evolve into biological sensory data, perhaps eliminating the need for a language in cases such as temperature and light control. However, gestures might always be useful for architectural components such as openings.

The main advantage to using building components as interfaces instead of devices is, of course, hands-free control. This would be most appropriate in settings where the user may find it too cumbersome to carry a hand-held interface, or in any situation or environment that might be harmful to an electronic device. Gestural control of dynamic architectural space would be most beneficial in athletic, swimming, or spa facilities, and also in environments with extreme weather conditions.

figure 12
The evolution of gestural language.

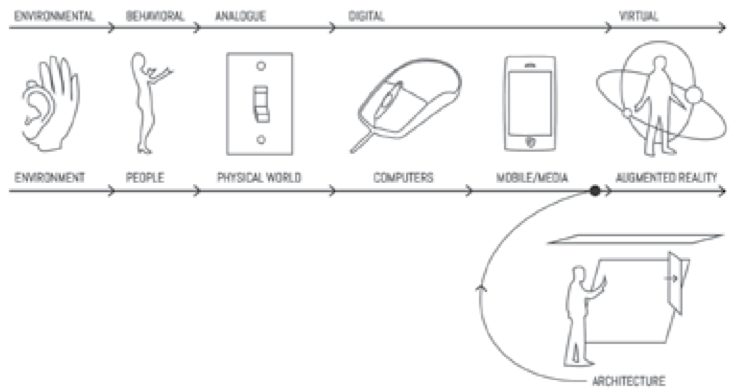

figure 12

Exciting possibilities exist for augmented reality to include gestural languages which evolve into a type of dance which affects or transforms the surrounding environment (physically moving building components) without physical labor, while actually improving the body-space relationship that voice control and similar techniques continue to threaten. This relationship is extremely important in architecture and the world—people have a natural tendency to manipulate their surroundings through touch. The experience of architecture may be at first, and primarily, visual, but it is secondly and most crucially physical. We use our eyes to experience an architectural composition in 2D, almost like a painting. However, the most engaging experience of architecture comes as the eyes negotiate distances, proportions, and materials in relation to the body. This is a physical relationship and is always subsequently verified by movement through and physical interaction with the building components. Interaction, or "play," with the physical world is crucial to the way humans learn to socialize and understand reality. The next phase of gestural languages to control interface devices, and eventually the entire built environment, should reflect this relationship and ideology.

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WORK IN PROGRESS

CROWDSOURCING ARCHITECTURE:
A DISRUPTIVE MODEL IN ARCHITECTURAL PRACTICE

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ABSTRACT

This paper discusses the use of crowdsourcing as a new approach for architectural design acquisition. We will give an overview of the concept of crowdsourcing, and elaborate on its particular application in architecture via concrete projects executed on Arcbazar, a first-of-its-kind crowdsourcing platform for architectural design services. We argue that online crowdsourcing platforms can have an immense impact on smaller-scale design challenges, e.g., home remodeling projects and landscape and interior design challenges, and can potentially carry these often neglected projects into the architectural design sphere. In this paper we will discuss the methods and techniques of architectural crowdsourcing and illustrate the processes and outcomes through a series of projects: a remodeling project for a closet; an interior design challenge for a dining space; and a layout problem for an apartment complex. We will then evaluate the protocol and outcome of architectural crowdsourcing, and convey the professional and popular media response to this new method of architectural design acquisition.