Architectural Robotics: Intelligent and Adaptable Built Environments

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Abstract
Robotics embedded in our built environment will increasingly support and augment everyday work, school, entertainment, and leisure activities. *Archibots,* a full-day workshop at *Ubicomp*, aims to identify opportunities and challenges in research and education in the emerging area of "Architectural Robotics" - intelligent and adaptable physical environments at all scales. For *Archibots 2009,* we seek position papers representing diverse perspectives from the extended ubicomp community exploring possibilities and defining an agenda for Architectural Robotics for the year 2019 and beyond. Workshop participants will discuss these perspectives and then, in teams, sketch short videos to envision possible futures. The collected videos of the workshop are intended to stream to the Video Program. The organizers plan to publish selected position papers as an edited book or special issue of a journal, and further relations with industry and allied disciplines.

Keywords
Robotics, Architectural Design, Human-Centered Computing

ACM Classification Keywords
H.1.2 User/Machine Systems, H.5.3. Group and Organization Interfaces, I.2.9 Robotics, J.4 Social and Behavioral Sciences

Introduction: Topic

I can imagine a future in which robotic devices will become a nearly ubiquitous part of our everyday lives.
- Bill Gates [3]

Throughout history the emergence of new technologies has reshaped our built environment and so, society. Roman arches afforded more freedom of movement – physically and socially – across thresholds. Flying buttresses allowed light to magnificently penetrate once-heavy walls. Reinforced concrete, structural steel, and free-plan organizational systems accommodated conventions of people, at work and at play, on a massive scale. Today we are embedding information and communication technologies (ICT) into the physical fabric of the built environment, mostly as: (1) building facades and other architectural surfaces acting as computer displays; and (2) smart control of heating, air conditioning and lighting for maintaining human comfort. ICT can intelligently move digital bits across building surfaces or temperature-controlled air through building interiors. Most important to this workshop: *embedded ICT can intelligently move mass to create an adaptive, physical-digital built environment.*

Decades ago Negroponte anticipated the prospect of such an "Architectural Robotics" in his vision of "…a man-made environment that responds to and is 'meaningful' for him or her" [8]. *Wired* editor Kevin Kelly has since imagined a "world of mutating buildings" and "rooms stuffed with co-evolutionary furniture" [5]. And while Bill Gates envisions "a robot in every home," [3] William J. Mitchell, former Dean of MIT's *School of Architecture and Planning*, sees homes "as robots for living in" [7]. And recently, the Herman Miller company published the monograph *Always Building,* provocatively subtitled: *the Programmable Environment [6].* Something is surely in the air.

Current research in robotics, including modular self-reconfigurable robots, heralds more significant changes in the built environment. Architectural Robotics raises questions such as: *How will we program buildings? How will buildings recognize activities taking place inside (e.g., sensor fusion)?* and *How will designers, including end-users, associate activities with desired building configurations?*

Architects typically anticipate how people will inhabit buildings and how buildings will respond to a range of possible local conditions. In designing Architectural Robotics, however, there is a fundamental difference: designers engineer a responsive system that actively engages with inhabitants and local conditions in real time. Whereas a conventional building has a limited range of responses to dynamic, changing conditions, an Architectural Robotics is bound together with its users and local conditions in a designed performance.

Architectural Robotics must go beyond simplistic formal achievements; it must explore ways for improving life, enhancing existing places, and supporting human interaction. Architecture and technology – particularly, an Architecture-Robot hybrid – must support human activity, respond naturally, and perform according to our needs and wants. Architectural Robotics must also

complement and redefine our urban living patterns. Answers to life problems and opportunities will come not from computational or robotic solutions alone, but through the way these technologies, embedded in the built environment, help advance the interaction among people and their surroundings to create places of social and psychological significance. For philosopher Andrew Feenberg, “technology is not simply a means but has become an environment, a way of life” [2]. An Architectural Robotics is more than an aesthetic search, a stylistic possibility, or a technological quest; it is a way to develop new spatial patterns in support of human activities.

Realizing an Architectural Robotics presents new and difficult challenges to research and education in Architecture (and its allied arts), Computer Science and Engineering, Electrical Engineering, and Human Factors Psychology. The development of new spatial patterns supporting human activities demands the attention of collaborative teams. Towards educating a new generation of investigators from these disciplines, the organizers have offered classes requiring student collaboration across the disciplines to promote knowledge exchange. Our collaborative research and educational activities cultivate in architects, scientists, engineers and human factors psychologists of this and future generations new vocabularies and understandings that promise both novel design propositions and the flourishing of the individual disciplines. This strategy is clearly warranted if the “future of design,” as Donald Norman describes, is “that of smart, intelligent devices, where almost everything will have a microprocessor built in, plus motors, actuators, and a rich assortment of sensors, transducers, and communication devices”[9].

Much of the above is, of course, well understood in the ubiquitous computing community. By focusing on robotics (i.e., actuation as well as sensing and planning) the workshop aims to anticipate the coming integration of computationally driven mass-moving technologies in the built environment. And, by drawing the architectural design and engineering communities to the Ubicomp conference the workshop aims to begin a dialog between these groups that can only enhance the quality of the information-integrated built-environment.

Workshop

This workshop aims *to identify opportunities and challenges in research and education in the emerging area of robotics technologies embedded in the built environment*. The workshop will convene researchers, investigators, students and industry participants who are envisioning and engineering an “Architectural Robotics”. Workshop participants will share research and teaching in Architectural Robotics with the intent to catalyze future knowledge exchange, collaboration and growth. The workshop aims to foster a viable interdisciplinary science and engineering community in Architectural Robotics. One intended outcome is the publication of a collection of position papers and references as well as Web sites and other media to define the emerging area of Architectural Robotics research.

This interdisciplinary workshop will bring together from different domains researchers who work in Architectural Robotics. The collaborative activities undertaken in the workshop will cultivate new vocabularies of design and ways that complex engineered systems can respond to human needs and wants, developing theories,

frameworks, and working methods for reconfigurability, reliability, controllability, and usability. Architectural Robotics will require sophisticated algorithms for sensing and inferring the occupancy, activities, and external conditions of a building that trigger reconfiguration, as well as planning and routing. The work will also contribute to our understanding of how to apply new technologies and human-centric design methods to improve traditional complex systems such as buildings. The educational activities in the workshop will explore methods of teaching multidisciplinary classes that bridge the academic cultural gaps that separate engineering, human-centered design, and architecture and its allied design and art practices.

Many workshop participants will have direct experience teaching in this field. Together, participants will consider such questions of pedagogy as: *How to educate students from these different backgrounds to collaborate productively in teams?* and *What tools could further teaching and learning in the design and implementation of Architectural Robotics?*.

The gradual embedding of robotics throughout the built environment will have a broad impact on society as these technologies support and augment everyday work, school, entertainment, and leisure. A key agenda item for the proposed workshop will be to anticipate particular impacts of Architectural Robotics; early applications will likely be in health care, in support for physically disabled people, and empowering a growing population wishing to age in place, as well as in intelligent work spaces responsive to changing needs, consuming less floor area, and reducing energy costs. What is clear now is that the buildings of tomorrow will actively respond to a variety of forces, including weather, security, and human needs.

Recent Meetings on Like Topics

Two *CoBuild* conferences (Darmstadt 1998 [1] and Carnegie Mellon 1999) brought together researchers working on “cooperative buildings”; the proceedings of these workshops were published by Springer as *Lecture Notes in Computer Science* [10]. The findings of these conferences are now a decade old, and their concerns were broader than the application of robotics to the built environment. In January 2008, the University of Aarhus, Microsoft Research UK, and EPFL co-hosted a workshop, *Interactive and Adaptive Furniture* [4],which included 25 invited participants from across computer science and engineering (several from robotics), social scientists, and designers and architects. The workshop featured individual presentations by participants and collaborative applied “exercises” that promoted exchange, definition of the field, and the potential for future work. The structure and topic of *Interactive and Adaptive Furniture* were compelling. However, the consideration was limited to small-scale environmental works (furniture) that were not inhabitable shelters (buildings), not particularly complex, and not supportive of more urgent needs and aspirations of an increasingly digital society.

Organizers

Keith Evan Green is Associate Professor of Architecture and Director of *Intelligent Materials and Systems for Architecture* (IMSA) at Clemson University. IMSA is a research group partnering the Departments of Architecture, Materials Science & Engineering, and Electrical & Computing Engineering. Green has worked on intelligent, robotic environments including, as PI,

the “Animated Work Environment” project supported by the U.S. National Science Foundation.

Mark D Gross is Professor of Computational Design at the School of Architecture, Carnegie Mellon University. He has worked on constraint programming languages for computer aided design, sketch and diagram recognition, and computationally enhanced construction kits. He serves as program chair for ACM Creativity & Cognition 2009 (C&C’09) and associate chair for ACM Interaction Design for Children (IDC ‘09), co-organized a workshop on tangible interaction in design at Design Computing and Cognition 2006 and a SIGCHI workshop on sketching and pen-based interaction (2001).

Call, Participation and Support

The organizers invite to the Workshop the most promising, knowledgeable, and diverse mix of researchers, students and visionary thinkers across disciplines including Architecture, Computer Science and Engineering, Electrical Engineering, Sociology, and Human Computer Interaction. The workshop will receive funding to defray participant costs for selected position papers under a U.S. *National Science Foundation SGER* Award (IIS-0925238). The organizers especially invite members of the Ubicomp community to participate.

The URL for all aspects of the Workshop is www.Archibots.org

Who will attend?
The workshop on ubiquitous computing and Architectural Robotics will bring together researchers and educators who work on the design of intelligent and responsive buildings that embed sensing and actuation. The workshop organizers aim to attract participants from traditional Ubicomp communities as well as architectural design, civil and architectural engineering, and sociology. The workshop will comprise a mix of faculty members and graduate students; academics, professionals, and industry researchers; and computer scientists, engineers, and architects and designers.

How to attract submissions and/or participants?
The organizers will attract submissions and participants through their colleagues in Architecture, Robotics, design engineering and the research communities of CHI, Pervasive, Tangible Interface and Ubiquitous computing. In addition to personal contacts, the workshop organizers will use email lists and blog postings to reach potential participants. Financial support from the U.S. National Science Foundation for workshop costs and participants’ travel will make it easier to attract participants, especially those who do not ordinarily attend Ubicomp. As well, the workshop organizers will seek representatives from the building and furniture industries (e.g., Steelcase); consumer electronics (e.g., Samsung, Bang & Olufsen); electronics and software industries (e.g., Intel, Microsoft, Google), professional and experimental architecture firms (e.g., Foster, Oosterhuis); and government stakeholders that manage large numbers of buildings (e.g., GSA, VA).

Topics of Interest

Topics include, but are not limited to, the following:

- Models of activity sensing and recognition
- Large-scale actuation and mechanisms

- Modular re-configurability in buildings
- Sustainability, Energy, and Environmental Impacts
- Interacting with Architectural Robotics
- Social impacts: People and Architectural Robotics
- Form and Design of Architectural Robotics
- Safety & security in robot-enhanced built environments
- Work, play & learning in robot-enhanced buildings.
- Aging in place and other assistive applications
- Architectural Robotics and its interfaces with other ubiquitous technologies.

Pre-Workshop Activity

Prior to the workshop the organizers will circulate participants' position papers and supporting materials (e.g., videos, web sites). Participants will be asked to review these materials in advance.

Activity-1: Oral Presentation

The first 90-minute session of the workshop will be devoted to a brief overview of all participants' work. A series of questions and perspectives that the organizers develop will frame discussion. Based on these presentations the organizers will assemble interdisciplinary teams of participants for a design exercise.

Activity-2: Design Exercise to Video

These mixed teams will engage in an applied design-vision exercise aiming to catalyze future knowledge exchange, collaboration and growth. Demonstrations of the collaborative design exercise will be recorded in video format. The resulting short videos will feed directly into the video program of Ubicomp 2009. Technical requirements for the design exercise will be communicated to all participants ahead of the workshop and will be limited in nature.

Activity-3: Identifying Key Topics, Challenges and Opportunities

Following from this design exercise and in discussions among all participants the workshop will identify and record key research and education topics in Architectural Robotics that can catalyze and advance the emerging field.

Post-Workshop Activity: Publication

The Workshop will result in the publication of: (1) a collection of the submitted position papers; (2) a collection of references in the field including academic papers, Web sites and other media; and (3) a joint position paper from the Workshop that identifies opportunities and challenges in the field.

The organizers intend to publish the proceedings as a monograph, in print and/or on-line, with the aim of reaching the widest possible community of researchers, educators, students and industry. Upon confirmation of participants, the workshop organizers will offer a publication proposal to Taylor & Francis (Spon and Routledge), MIT Press, Springer, and ACTAR, and will also consider a Creative Commons license for on-line publication. Following the workshop the organizers will explore editing a journal special issue; (e.g., Personal and Ubiquitous Computing; *Artificial Intelligence in Engineering, Design, Analysis & Manufacturing (AI-EDAM*); *Co-Design* Journal); an overview article on the emerging area of ubiquitous computing and Architectural Robotics in (for example) *Communications of the ACM*; *IEEE Computer* magazine; a shorter summary piece in *Interactions*.

The Potential for a Recurring Workshop

The organizers envision the "Architectural Robotics" Workshop as potentially recurring at future Ubicomp conferences. By sponsoring the Workshop in Architectural Robotics, the U.S. National Science Foundation supports this ambition to build this community, and the recurring Workshop would be a key vehicle for this. Building the Architectural Robotics community through successive Ubicomp workshop offerings broadens participation in Ubicomp and intensifies research efforts within this emerging community.

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