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Inhabiting Adaptive Architecture

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Adaptive Architecture concerns buildings that are specifically designed to adapt to their inhabitants and to their environments. Work in this space has a very long history, with a number of adaptive buildings emerging during the modernist period, such as Rietveld's Schröder house, Gaudi's Casa Batlló and Chareau's Maison de Verre. Such early work included manual adaptivity, even if that was motor-assisted. Today, buildings have started to combine this with varying degrees of automation and designed-for adaptivity is commonplace in office buildings and eco homes, where lighting, air conditioning, access and energy generation respond to and influence the behaviour of people, and the internal and external climate.

In addition, over the last two decades, the availability of cheaper computation, more accessible programming interfaces and a wider spread of the necessary development skills has exponentially increased the level of experimentation in this exciting field. This is very visible in a series of publications that discuss interactive[1], responsive[2] and robotic architecture[3]. Working in this space is a loose network of research labs for example at MIT, UCL and TU Delft, which pushes this work, crossing the disciplinary boundaries between Architecture, Computer Science, Engineering, Social Sciences and Art.

With the aim to support the community in not loosing the conceptual and historical overview of this work, we are maintaining a categorised view of adaptive architecture at: http://www.adaptivearchitectureframework.org. This interactive map classifies the field by highlighting four top-level categories: in response to what is architecture responsive, what elements are adaptive, what methods are employed and what effect that adaptivity has. The map is illustrated with an extensive list of historical examples, and it also allows for crowd-sourced extensions of the map.

1. Inhabitation

While important, creating such overviews, whether via the aforementioned books, research group websites or indeed the interactive map, cannot tell us much about how people inhabit such structures.

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1 Fox, Michael Aug, and Miles Kemp. 2009. Interactive architecture. New York: Princeton Architectural Press.
2 Beesley, Philip, and Omar Khan. 2009. "Responsive Architecture / Performing Instruments." Situated Technologies Pamphlets 2 (4).
3 Bier, Henriette. 2014. "Robotic Building(s)." Next Generation Building 1 (1):83-92. doi: 10.7564/14-NGBJ8. and Green, Keith Evan. 2016. Architectural robotics : ecosystems of bits, bytes, and biology. Cambridge, Massachusetts: The MIT Press.

But, it is critical to develop such an understanding alongside prototypes, if this experimental work is designed to find wider use and acceptance.

A diverse range of previous publications can frame the broader context of developing such an understanding. Banham traced the early introduction of technologies into architecture[4]. Weiser proposed the merging of computing and environment [5]. Suchman demonstrated how technology must be understood in the context it is developed for[6]. And finally, Brand highlighted how buildings become adapted well beyond the original intentions of architects by inhabitants over time[7].

In the above context, Adaptive Architecture must be understood as a social-technical concern. Understanding must involve understanding the technology and social interaction with, within and through it. How people might inhabit adaptive architecture has been a focus of research at the Mixed Reality Lab, Nottingham. We address this question by designing, constructing and evaluating prototypes to expose basic and applied knowledge about the relationship between people and adaptive architecture.

In what follows, four pieces of experimental work in this space will be briefly introduced and discussed, before describing the generalised feedback loops that emerge between adaptive environments and inhabitants.

2. Mixed Reality Architecture

The first work is Mixed Reality Architecture (MRA). It embeds always-on audio and video connections within an office environment. MRA combines research into Media Spaces[8] and into shared virtual environment[9] with an understanding of architecture influencing social interaction through its topology[10].

Each connected office has a large screen, a video camera, microphones and speakers, and it is represented by an adaptive cube in a shared virtual environment, as shown in Figure 1.

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4 Banham, Reyner. 1984. The architecture of the well-tempered environment. 2nd ed. Chicago: University of Chicago Press.

5 Weiser, Mark. 1991. "The Computer for the Twenty-First Century." Scientific American 265 (3):94-104.

6 Suchman, Lucy A. 1987. Plans and situated actions : the problems of human machine communication. Cambridge: Cambridge University Press.

7 Brand, Stewart. 1994. How buildings learn : what happens after they're built. London, UK; New York, USA: Viking.

8 Mantei, Marilyn M., Ronald M. Baecker, Abigail Sellen, Bill Buxton, and Thomas Milligan. 1991. "Experiences in the Use of a Media Space." CHI, New Orleans, USA.

9 Greenhalgh, Chris. 1999. Large scale collaborative virtual environments, Distinguished Dissertations. London, UK: Springer.

10 Hillier, Bill, and Julienne Hanson. 1984. The social logic of space. Cambridge, UK: Cambridge University Press.

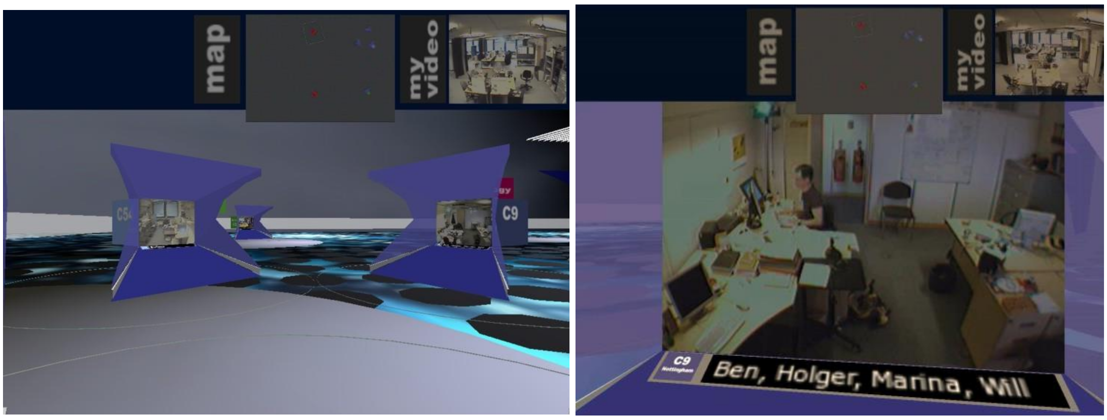

Figure 1: View into shared virtual environment of Mixed Reality Architecture (left) and view into one of the connected offices, showing map and video mirror of one's own space (right)

Any occupant of any of the connected offices can virtually move their office to be closer to any of the other office. When two or more offices are close, audio and video streaming are enabled.

A longitudinal study in a high-network bandwidth academic context, spanning research partners at University College London and Bath universities, showed how MRA enabled and shaped spontaneous and planned interactions. It replicated spatial aspects of communication, especially how this becomes accountable to others[11]. Our attempts to get this adopted outside academia failed. Partly this was because of technical issues, available networking speeds being too slow at the time. Partly, it was due to differences in organisational culture, where hierarchies in commercial organisations are a lot less flat than in the academic organisations we had worked with previously.

Architecturally, the most important outcome was the immediate adaptivity of topology and how architecture, technology and people shape this. In MRA, it is inhabitants (not architects) who adapted architectural topologies on the fly to enable social interaction. The resulting ever-changing topologies then in turn shape what social interaction is possible[12].

3. Screens in the Wild

A second project to highlight is the Screens in the Wild project, which investigated the concept of connecting remote physical places in a different, an urban context. This occurred with the background of the development of interactive media facades[13] and the ubiquitous use of digital screens for advertising in urban spaces being criticised for not being relevant to communities that are being faced with them[14].

In collaboration with UCL, we developed the Screens in the Wild network to involve communities in the content of such screens. We had four nodes in total. Each node was installed in a

[11] Schnädelbach, Holger, Alan Penn, Philip Steadman, Steve Benford, Boriana Koleva, and Tom Rodden. 2006. "Moving Office: Inhabiting a Dynamic Building." CSCW, Banff, Canada.

[12] Schnädelbach, Holger. 2012. "Hybrid Spatial Topologies." Journal of Space Syntax 3 (2):204-222.

[13] Wiethoff, Alexander. "Designing Interaction with Media Facades: A Case Study."

[14] Schieck, Ava Fatah gen., Ghislaine Boddington, and Peter Fink. 2009. Framework for the implementation of urban big screens in the public space. London, UK: University College London. and Struppek, Mirjam. 2006. "The social potential of Urban Screens." Visual Communication 5 (2):173-188. doi: 10.1177/1470357206065333.

'shop front'. It could be interacted with from the outside using a through-glass touch technology. Each node had a screen, a camera, speakers and a microphone. The network was unique in the way that it provided for networked interaction between multiple city areas.

Figures 2: Screens in the Wild interactive the screen on the facade of a cinema and media centre. Walk-up interaction helping to define urban space

We engaged people in workshops and meetings to discuss what purpose such screens have in enhancing urban life. And we used the results to generate ideas and content for the screens[15]. The results led to sustained engagement of people on the streets of the connected places. We implemented a whole host of different applications: From slide and video slide shows to something to express your mood, something to teach you about ADHD and an urban photo booth. With that photo booth, we captured more than 40,000 photos[16].

People appreciated the ad-hoc, free engagement having a very low entry barrier for engagement. The screens were also valued for adding to urban life and the street scene and this is were the greatest architectural impact lied, making aspects of urban space that usually corporate accessible to all parts of society, at least in principle. Organisationally, it was difficult to keep content fresh and we did not find a route to commercially support the type of content that we found was engaging communities.

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[15] Motta, Wallis, AvaFatahgen Schieck, Holger Schnädelbach, Efstathia Kostopoulou, Moritz Behrens, Steve North, and Lei Ye. 2013. "Considering Communities, Diversity and the Production of Locality in the Design of Networked Urban Screens." In Human Computer Interaction - INTERACT 2013, edited by Paula Kotzé, Gary Marsden, Gitte Lindgaard, Janet Wesson and Marco Winckler, 315-322. Heidelberg, Germany: Springer.

[16] Memarovic, Nemanja, Ava Fatah gen Schieck, Holger Schnädelbach, Efstathia Kostopoulou, Steve North, and Lei Ye. 2015. "Capture the Moment: "In the Wild" Longitudinal Case Study of Situated Snapshots Captured Through an Urban Screen in a Community Setting." CSCW, Vancouver, Canada.

4. ExoBuilding

The ExoBuilding series of prototypes link physiological data from inhabitants (e.g. heart beat, respiration, skin conductance) to actuations in the environment (e.g. movement, sound, graphics). The most commonly explored version maps respiration to movement: when its inhabitant inhales, the building increases in size and when they exhale, it decreases in size. ExoBuilding was developed in the broad context of physiological computing[17], making use of such personal data as an interaction input and developments around the 'quantified self', making data part of all aspects of a person's life[18].

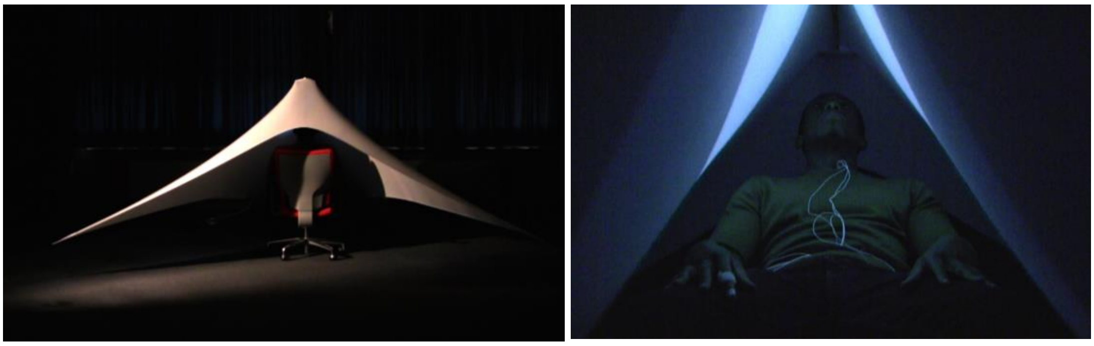

Figure 4: ExoBuilding mapping physiological data of its inhabitant to its appearance, form and sound scape (left) & ExoBuilding interior (right)

ExoBuilding creates an immersive, multi-sensory and embodied experience. It moves the air in and out, creating a gentle breeze. The fabric occasionally touches your hand. The motors sound a little like breathing and your heartbeat vibrates the floor. Inhabitants see the blue circle in front of them grow and shrink in the rhythm of their respiration. From very early on, reactions to this prototype of experimental architecture were very distinct, describing the generated experience as very relaxing and generating a deep connection to one's own body[19].

Prompted by this, we stepped through a series of lab studies to investigate this prototype in more detail. In a first study, we compared a biofeedback condition, with regular movement of the structure and with no adaptation at all. We found that biofeedback-driven Adaptive Architecture can indeed trigger behavioural and physiological adaptations without giving people instructions. Specifically, it supports people to breathe slower and more deeply and this triggers deep relaxation in some people[20]. We then compared the biofeedback loop between people inside ExoBuilding to people sitting outside ExoBuilding. We found that Immersion creates embodied interactivity and relaxation compared to the same non-immersed interactivity, where the environment remains an external object[21]. In a third lab

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[17] Fairclough, Stephen, and Kiel Gilleade, eds. 2014. Advances in physiological computing, Human-computer interaction series. London ; New York: Springer.
[18] Wolf, Gary, and Kevin Kelly. 2014. "Quantified Self: Self Knowledge Through Numbers." Accessed 02/01. http://quantifiedself.com.
[19] Schnädelbach, Holger, Kevin Glover, and Alex Irune. 2010. "ExoBuilding - Breathing Life into Architecture." NordiCHI, Reykjavik, Iceland.
[20] Schnädelbach, Holger, Ainojie Irune, David Kirk, Kevin Glover, and Patrick Brundell. 2012. "ExoBuilding: Physiologically Driven Adaptive Architecture." ACM Transactions in Computer Human Interaction (TOCHI) 19 (4):1-22. doi: 10.1145/2395131.2395132.
[21] Schnädelbach, Holger, Petr Slovák, Geraldine Fitzpatrick, and Nils Jäger. 2016. "The immersive effect of adaptive architecture." Pervasive and Mobile Computing 25 (1):143-152. doi: 10.1016/j.pmcj.2015.07.006

study, we shifted from biofeedback control to an automated movement, hiding this shift from people. Our finding was that, following immersive feedback; regular movements can be used to trigger behavioural changes as well. This hints at the fact that even without biofeedback, architecture could measurably affect our physiological responses[22] .

Finally, in a first non-experimental application of ExoBuilding, we collaborated with yoga teachers and students. The control of breathing is an essential part of Yoga practice. The work involved adaptations to yoga practice, for example a concentration on aspects of yoga that fit into the raised ExoBuilding as you can see of the images. And, these adjustments also resulted in change to ExoBuilding itself, mainly in the way it is controlled by one or two yoga practitioners. We found that ExoBuilding can provide new and useful information to teachers about the current internal state of their students, basically surfacing internal states for everyone to see. And, when a machine drives the environment in a regular and predictable pattern, self-reported group cohesion improves dramatically[23].

5. Move

Most recently, we have started to experiment with a movement-controlled prototype. The broader architectural context is provided by the growing interest in physical movement in buildings[24] and robotic control of such movements[25]. This is coupled by the broad availability of movement detection sensors.

MOVE is a hardware and software platform that allows experimentation with mappings of human movement to architectural movements. MOVE detects key body movements of a single person via a Kinect and flexibly maps them to up to 16 engines via Processing and Phidgets. It can be used to actuate architectural building components of different types and it allows the scaling of movements and frequency mappings[26].

Initially this was to explore the creation of architectural form through body movement. From the standpoint of a single inhabitant, ego-centric form is created and ‘makes sense’ for that inhabitant. We have also explored the use of MOVE in the context of the Tetsudo martial arts. Study participants fed back how such an adaptive environment can be useful to reflect back movement in way that can be studied and how performers adapt their behaviour to what is technically available.

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[22] Jäger, Nils, Holger Schnädelbach, Jonathan Hale, Dave Kirk, and Kevin Glover. In Press. "Reciprocal Control in Adaptive Architecture." Interacting with Computers.

[23] Moran, Stuart, Nils Jäger, Holger Schnädelbach, and Kevin Glover. 2016. "ExoPranayama: a biofeedback-driven actuated environment for supporting yoga breathing practices." Personal and Ubiquitous Computing 20 (2):261-275. doi: 10.1007/s00779-016-0910-3.

[24] Schumacher, Michael, Oliver Schaeffer, and Michael-Marcus Vogt. 2010. MOVE: Architecture in Motion - Dynamic Components and Elements: Birkhäuser.

[25] Bier, Henriette. 2014. "Robotic Building(s)." Next Generation Building 1 (1):83-92. doi: 10.7564/14-NGBJ8. and Green, Keith Evan. 2016. Architectural robotics : ecosystems of bits, bytes, and biology. Cambridge, Massachusetts: The MIT Press.

[26] Schnädelbach, Holger. 2016. "Movement in Adaptive Architecture." In Spatial Cultures: Towards a New Social Morphology of Cities Past and Present edited by Sam Griffiths and Alexander von Lünen, 320. London: Routledge / Ashgate.

Figure 5: MOVE protoype used by a Tetsudo martial arts performer

6. Feedback loops in Adaptive Architecture

In some sense, the prototypes presented above are very diverse. Diverse in the settings that they are employed in, the way that they are generating or integrating with architectural space, the aims for their use, the employed technologies and the way that they have been evaluated. The overarching aim for all of them though has been to better understand what it means to inhabit Adaptive Architecture; and that is being built in many different guises and circumstances.

There are also clear commonalities. All presented prototypes are hybrids, combining physical space with digital interactivity. The architectural material itself often becomes what people interact with, instead of architecture acting as a site of interaction interfaces only. Investigating the prototypes' relationships with their inhabitants then also demonstrates another commonality, namely the ways in which interaction between inhabitant and environment can be described as a feedback loop.

Through some technology, a chosen set of personal data is captured from an inhabitant or inhabitants (e.g. often a combination of their interaction input, voice and video, physiological data, movement data). This data can then be used in its raw format. It can also be manipulated in different ways, it could be aggregated incorporate multiple people. It could also be interpreted, attempting to infer something about the state of the inhabitant, such as their psychological or mental state. The filtered data is then used to drive adaptations in a space. Such actuations can be anything that it is possible to actuate in architecture from the lighting infrastructure to environmental controls or media display. These have an effect on architecture, for example on the architectural topology, the appearance, information content and interactivity of facades, the space created by architecture or indeed architecture's form, as seen in the prototype presented in this abstract. These changes then in turn have an effect on the inhabitants, feeding back to the person, contributing one of the original streams of data for adaptations. For example, the environmental effects triggered might mean that inhabitants feel more comfortable, feel more relaxed or indeed more anxious.

Actions and reactions by both the building and its inhabitants influence each other. In this way, buildings and inhabitants become interaction partners in a very specific way and it is this feedback loop that requires much further investigation in future.

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