INTER-ACTIVE DESIGN

Behnaz Farahi, Neil Leach (eds.)

INTER-ACTIVE DESIGN

Towards a Responsive Environment

Birkhäuser
Basel

Table of Contents

Part II:
New Kinds of Interaction

Part III:
Material Interactivities

Part IV:
Transdisciplinary Approaches

Conclusion

Preface

Welcome to Interactive Design: Towards a Responsive Environment. We are thrilled to share with you our fascination with the relationship between human beings and their environment. Through our exploration of various ways of using technology to create responsive environments that adapt to the needs, emotions and behaviours of their users, we have compiled this book as a culmination of research and projects by some of the most prominent practitioners and thinkers in the field of interactive design.

Our goal is to provide a theoretical and practical framework that designers and researchers can use to create meaningful and engaging interactive experiences. We draw upon various fields of design, including architecture, product design and urban design, to illustrate the key concepts and techniques.

This book is intended for anyone interested in the intersection of technology and design, including designers, researchers, educators and students. Whether you are a seasoned professional or a curious beginner, we hope that this book will inspire you to explore the possibilities of interactive design and create responsive environments that enhance the human experience.

We would like to express our gratitude to all our colleagues, collaborators, and mentors who have supported us in this research. We would also like to thank CSULB and Tongji for their generous support towards the production costs of this book.

We invite you to join us on this exciting journey and hope you will find this book informative, inspiring, and thought-provoking.

Behnaz Farahi and Neil Leach

A Brief History of Interactive Architecture

Behnaz Farahi, Neil Leach

"Technology is the answer,
but what was the question?"

(Cedric Price, 1966)

The avant-garde designs of Archigram during the 1960s depicted a vision of the future in which architecture is interactive and responsive not only to its surroundings but also to human needs and desires. In projects such as Plug-in City, The Walking City, and Instant City, Archigram envisioned the transformation of architectural spaces by embracing technology and ideas from cybernetics. In his article "Living 1990: Archigram Group" Warren Chalk (1967) notes, "The push of a button or a spoken command, a bat of an eyelid will set these transformations in motion – providing what you want where and when you need it. Each member of a family will choose what they want – the shape and layout of their spaces, their activities and what have you". It was radical ideas such as these that launched the field of interactive architecture.

It may seem a little counterintuitive to attempt to write a history of interactive design, however cursory, since most aspects of computational design are premised on looking forward, rather than backwards. Indeed, in its present condition, research in interactive design and architecture seems to be governed by an experimental outlook premised on innovation and novelty, with the past serving largely as a repository of earlier experiments that help to define whether a contemporary project is itself original or not.

Moreover, as American media theorist Benjamin Bratton once commented, we are still in the "silent movies" era of computation (Leach, 2022). The history of digital design is indeed brief, but the history of interactive design is even briefer. One reason for this is that some of the technology intrinsic to interactive systems was not accessible until relatively recently. For example, computer-aided design software was popular in architectural offices from the 1980s onward, whereas Arduino, the microcontroller that has helped to make interactive design so accessible, was not introduced until 2005.

Nonetheless, the future is inextricably linked to the past. "Tomorrow", as the saying goes, "today will be yesterday". As such, past and future should be seen within a continuum, and an understanding of the past – however cursory – should be an essential component in addressing any futuristic venture, such as interactive design and architecture.

Cybernetics

The origins of interactive design in general and interactive architecture in particular can be traced back to the theory of cybernetics. The discourse of cybernetics emerged as a result of the Macy conferences from 1946 to 1953 (Pias, 2016). These conferences aimed to open up a new interdisciplinary field by connecting various disciplines, such as mechanical and electrical engineering, neurobiology, evolutionary biology, communications theory and psychology. Engineers, mathematicians and physiologists, such as

Norbert Weiner, Claude Shannon, Warren McCulloch and William Ashby, met and shared their ideas at these events (Pias, 2016).

In 1948, two years after the first Macy conference, Norbert Wiener coined the term "cybernetics" in his book *Control and Communication in the Animal and the Machine* (1948). Derived from the Greek word, *kybernetike*, meaning "governance", cybernetics looks at information feedback in order to "steer, navigate or govern a goal" in any intelligent system including biological, social and mechanic processes. As Weiner (1948) explains it, "Cybernetics combines under one heading the study of what in a human context is sometimes loosely described as thinking and in engineering is known as control and communication. In other words, cybernetics attempts to find the common elements in the functioning of automatic machines and of the human nervous system, and to develop a theory which will cover the entire field of control and communication in machines and living organisms".

As Dubberly and Pangaro (2005) point out, both living and non-living systems (machines) can have a purpose and therefore operate according to cybernetics principles. "Cybernetics focuses on the use of feedback to correct errors and attain goals. It has roots in neurobiology and found practical application during World War II in the development of automatic controls for piloting ships, airplanes, and artillery shells". Having said that, the scope of cybernetics is broad; it attempts to embrace not only the way in which humans interact with machines and systems, but also the way in which humans interact with one another.

The next phase came from 1968 to 1975 when Heinz von Foerster (2003) formulated his theory of second order cybernetics as a way of moving beyond the cybernetics of Wiener. It was an attempt to explore the role of the observer in the formation of systems through positive feedback. Although first order cybernetics was tied to the image of the machine, second order cybernetics more closely resembled organisms and biology by using noise as positive feedback. With positive feedback, a distorted message would reinforce the system's organisation and sometimes help the system to self-organise. As von Foerster (2003) notes, "A brain is required to write a theory of a brain. From this follows that a theory of the brain, that has any aspirations for completeness, has to account for the writing of this theory. And even more fascinating, the writer of this theory has to account for her or himself. Translated into the domain of cybernetics; the cybernetician, by entering his own domain, has to account for his or her own activity. Cybernetics then becomes cybernetics of cybernetics, or second-order cybernetics".

Although the science of cybernetics has had a significant influence on many researchers and practitioners, it is important to note that cybernetics has also faced considerable criticism. In *The Cybernetic Brain: Sketches of Another Future* (2011), Pickering responds to some of this. One of the criticisms is that cybernetics is often thought of as a militaristic science; responsible, for instance, for the development of autonomous anti-aircraft guns. Responding to this criticism, Pickering (2011) notes, "First, I think the doctrine of original sin is a mistake – sciences are not tainted forever by the moral circumstances of their birth – and second, I have already noted that Ashby and Walter's cybernetics grew largely from a different matrix: psychiatry". Another criticism of cybernetics concerns the notion of control, which has caused a certain degree of

suspicion. Pickering thinks that this is more a problem of modernity than cybernetics. Pickering (2011) answers, "Perhaps we have gone a bit overboard with the modern idea that we can understand and enframe the world". He thinks that British cybernetics was not "a scientized adjunct of Big Brother", but argues instead that we have to see it as an ontology of "unknowability" and "becoming" (2011).

At the heart of the theory of cybernetics was the notion of interaction. The English scientist, researcher and cybernetician, Gordon Pask, who had been introduced to Wiener's ideas in the early 1950s, developed his Conversation Theory (1970) in an attempt to model how humans and machines learn and construct knowledge through interaction. As Usman Haque (2007) notes, "It was a framework that accounts for observers, conversations, and participants in cybernetic systems". Pask was particularly interested in grounding conversation theory in authentically interactive systems that are not predefined but can develop a unique interaction with individuals. The bottom line in his theory is that this process is a circular one with potential for feedback correction and evolution. Otherwise, the system is just reactive. He goes on to differentiate between single-loop and multiple-loop interaction. Haque (2006) explains, "Multiple-loop interaction does not depend upon complexity; it depends upon the openness and continuation of cycles of response. It also depends on the ability of each system, while interacting, to have access and to modify each other's goals". In his paper "The Architectural Relevance of Cybernetics" (reprinted in this volume) Pask (1969) goes on to explore the connection between cybernetics and architecture.

In this context, it is important to note that "interactive architecture" needs to be distinguished from simple "responsive architecture". For a genuinely interactive architecture there has to be a two-way process or feedback loop. In other words, there needs to be a form of "interaction" and not merely a "reaction" or "response". The important word here is "conversation", within the context of conversation theory implying that the user and the device respond to one another through a form of feedback loop. For example, an appliance such as a refrigerator, where the light comes on automatically when the door is opened, could be described as merely "responsive" while many of the projects and papers presented in this book are examples of interactive design.

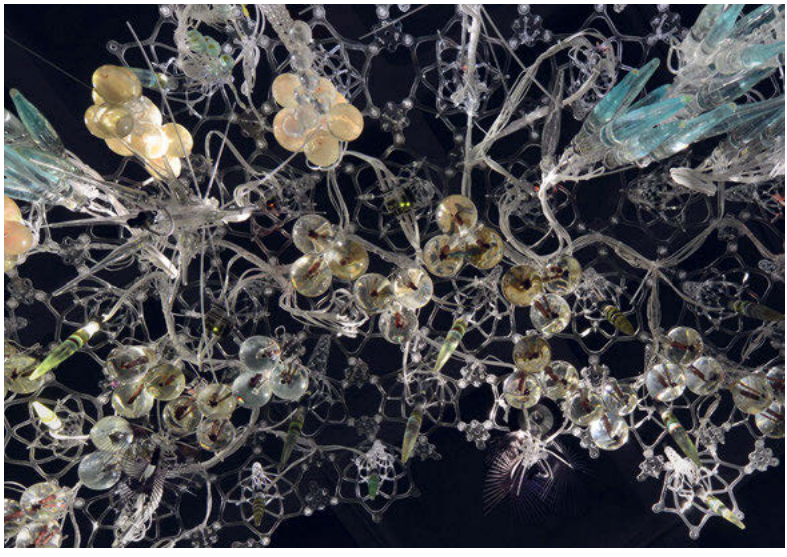


Fig. 1 *Spring Dragon Tail* by Philip Beesley Architect Inc. The permanent acquisition by the Shangdu Li corporation opened in October 2015 as part of the Interactive Watertown exhibition in Shanghai. Interactive systems within the Chun Long Tiao sculpture feature a new generation of proprioreceptive sensors, enabling internal feedback within networked Teensy microprocessor control systems.

Fig. 2 *Light Sculpture* by teamLab. Laser beams are used to create a collection of light planes constructing a spatial object where visitors will find themselves immersed in a complex, three dimensional reconstruction of space.

Cedric Price was perhaps the first architect to engage with the science of cybernetics and Pask's ideas from an architectural perspective. Price designed the unbuilt Fun Palace project (1961) in collaboration with Pask, who was then working at the Architectural Association School of Architecture as a "resident cybernetician, introducing the concept of underspecified goals to architecture systems" (Haque, 2007). Working in conjunction with the theatre director Joan Littlewood, Price designed a structure that was not simply responsive or pre-programmed, but that operated as an unpredictable reconfigurable space that was an articulation of second-order cybernetics, relying on computational systems to allow the structure to be both constantly adapting and indeterminate in its form and program. As Yiannoudes (2016) puts it, "Price emphasised the flowing and flexible character of the building's interior; corridors, rotating escalators and openings would be organised in such a way as to enhance the continuous flow of visitors, while mobile, temporary and inflatable components (walls and rooms), as well as movable floors, would allow space to stay free of boundaries; open and indeterminate". He further elaborates, "For Price, architecture should be an open process, an activity involving time, change and indeterminacy, rather than static form".

Reyner Banham was one of the first architectural historians to engage with cybernetics at a theoretical level. Banham illustrated his article "The Home is Not a House" (1965) with two projects conceived by François Dallegret, including The Environment Bubble. As Yiannoudes (2016) notes, "Banham's Environmental Bubble, a speculative proposal for such a cybernetic feedback mechanism, would use responsive technologies to dynamically engage with the local conditions, adapting to environmental changes. Its membrane could supposedly inflate at will and cater for rain, temperature and wind, blowing down an 'air-curtain' of either warmed or cooled conditioned air, where and when needed. This would be controlled by light and weather sensors". These ideas eventually fed into Banham's seminal book, *The Architecture of the Well-Tempered Environment* (1969), where he attempted to write an alternative history of architecture based not on typology or form, but environmental control systems, such as air-conditioning and ventilation.

Between 1970 and 1990 there were in fact multiple attempts to explore these ideas in schools of architecture: particularly at the Architectural Association in London through John Frazer, and the Architecture Machine Group at Massachusetts Institute of Technology (later to become the Media Lab) through Nicholas Negroponte. Frazer is an influential figure, particularly in bringing cybernetic ideas to architectural education and considering architecture as a form of artificial life. His influence can be seen in his book*, An Evolutionary Architecture* (1995), which describes 30 years of teaching experience at the Architectural Association. Frazer, along with Julia Frazer, acted as consultants for Price in his exploration of cybernetics, architecture and interaction: the Generator project.[1] However, the Fun Palace and Generator projects remained somewhat isolated forays into the domain of interactive architecture. They were very much ahead of their time, and made little immediate impact on mainstream architectural discourse, although these two projects have not been recognised as seminal moments in the history of interactive architecture. The Fun Palace, in

1 Frazer, John. DigitalFUTURES 'Legends' interview with Neil Leach. https://www.youtube.com/watch?v=_GE2PsI2Tdw&t=3058s, 2022.

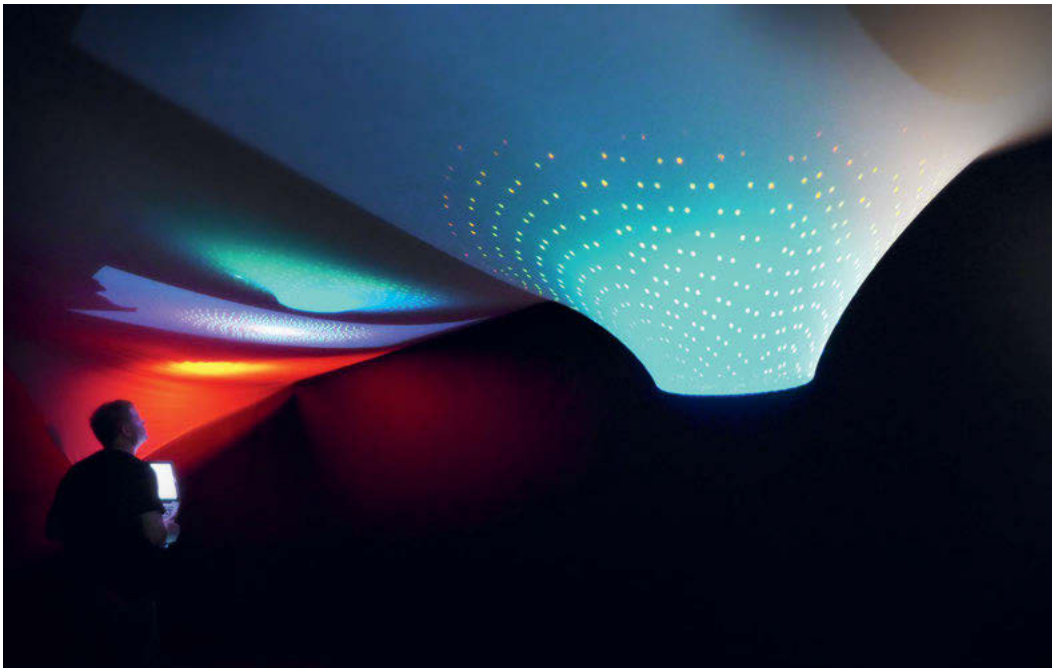


Fig. 3 Zaha Hadid Architects in collaboration with Kollision, CAVI and *Wahlberg*, 2013. The installation reacts to the visitors' movements – in shape and expression. At first glance the installation is a "normal" rectangular space – four walls, floor and ceiling. But the space changes as you enter it with the help of two laser scanner sensors that continuously gather information about visitors' positions in the space.

Fig. 4 Swing Time by Höweler + Yoon Architecture. Swing Time is an interactive playscape composed of 20 illuminated ring-shaped swings. The installation consists of custom-fabricated, form-welded polypropylene. LED lighting within the swing is controlled by a custom micro-controller, signalling the swing's activity level.

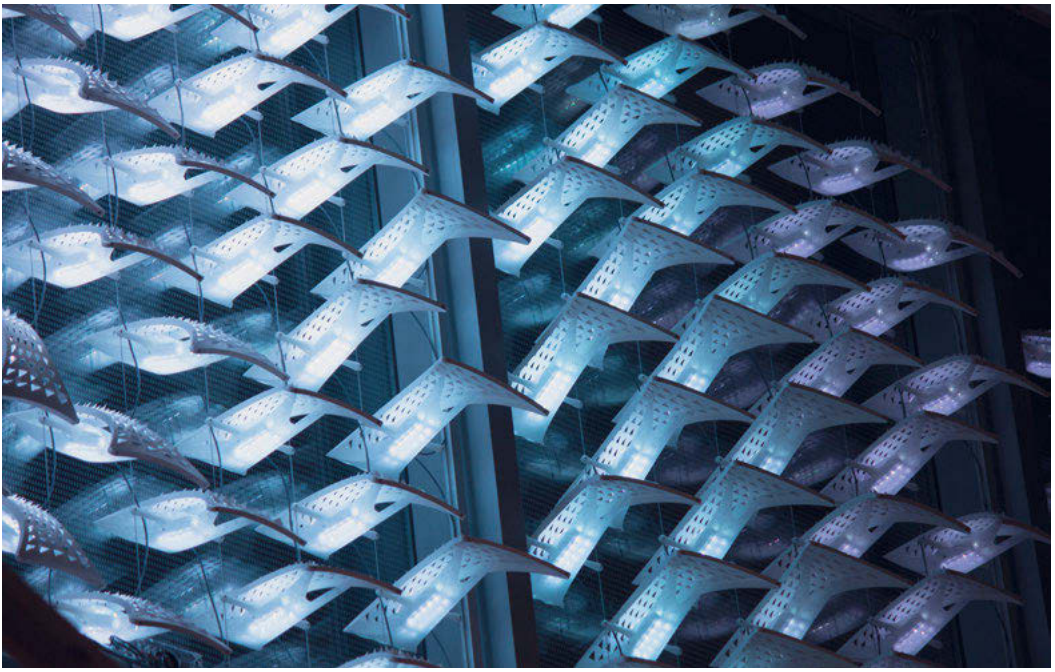


Fig. 5 *Lightswarm* by Future Cities Lab, 2012. Lightswarm is an interactive light installation in San Francisco that is in a state of perpetual flux. Responding to sounds harvested from the building lobby and the surrounding city, the site-specific artwork activates the façade with playful swarms of light.

Fig. 6 *The Borderless World* by TeamLab, 2016. This immersive installation transforms according to the presence of people and transcends the boundaries between people and the world.

particular, has left behind something of a legacy in the field of interactive architecture. An exhibition of the Fun Palace curated by Hans Ulrich Obrist was installed in the Swiss Pavilion at the 2014 Venice Biennale of Architecture.[2] The Fun Palace has also inspired a number of recent projects, including The Shed in New York designed by Diller, Scofidio + Renfro.[3] As Haque (2007) notes, "These collaborations were too far ahead of their time and were not fully grasped by the wider architectural community, but they did help to set the foundations for dynamic, responsive and authentically interactive environments".

By the 2000s, however, Arduino microcontrollers, embedded computation and sensor effectors began to become commercially available. These interactive technologies encouraged many architects and designers to see new possibilities in interactive architecture. As Michael Fox (2009) explains, "Interactive architecture began to gain a stronger foothold as ideas became both technologically and economically feasible".

This next phase comprised a series of experimental explorations that were confined mostly to the space of the exhibition or the architectural magazine. In the late nineties, interactive design was being taught at the Architectural Association, where the Design Research Laboratory had begun to explore the possibilities of responsive environments that could be programmed to mutate and change, with walls morphing into seats and floors, while furniture – chairs and desks – would be capable of migrating from room to room and arranging themselves in novel configurations for meetings or other events (Schumacher, 2002).

While these designs were easy enough to represent on the computer screen, early attempts to realise them met with varied success. At the Venice Biennale of 2000, for example, Hani Rashid and Greg Lynn ran a studio exploring their potential.[4] The net result, however – an inflatable structure installed in the Venice Giardini – seems crude in comparison to more recent interactive designs. Equally within the field of responsive design – as in the case of Jean Nouvel's pre-computational responsive façade on the Institute du Monde Arabe in Paris completed in 1987, but which failed soon afterwards – early responsive systems were always prone to breaking down, a problem that continues to plague interactive architecture.

More promising, perhaps, was the work coming out of the Netherlands, especially the designs of Kas Oosterhuis and Lars Spuybroek. Oosterhuis's Salt Water Pavilion and Spuybroek's adjacent H_2O Water Pavilion in Vrouwenpolder completed in 1997 were early pioneering efforts in using visually interactive spaces and structures. Oosterhuis went on to design a series of interactive installations, including various projects in the Muscle series (2002). Meanwhile, Spuybroek went on to design Son-O-House in Son en Breugel which was completed in 2002, an early acoustically interactive pavilion; and in 2003 he completed the D-Towers project in Doetinchem, an interactive light tower, designed in collaboration with the V2_ Institute, that responded to the moods of the inhabitants by changing colours (Spuybroek, 2004). The legacy of this pioneering Dutch tradition could be found in the interactive research at Hyperbody at TU Delft, established by Oosterhuis himself, and the work of leading Dutch interaction designers, such as Daan Roosegaarde and Anouk Wipprecht.

Also promising was Mark Goulthorpe's Aegis Hyposurface project (2003). Goulthorpe had won a competition for an interactive wall in Birmingham, whose

2 Stevens, Philip. 'Swiss pavilion takes visitors on a stroll through a fun palace at the Venice Biennale'. Designboom, accessed from https://www.designboom.com/architecture/swiss-pavilion-venice-architecture-biennale-06-19-2014/, 2014.

3 Diller, Elizabeth. DigitalFUTURES 'Legends' interview with Virginia Melnyk. https://www.youtube.com/watch?v=3hjcdOQ4Vqg, 2022.

4 Rashid, Hani; Lynn, Greg. Accessed from https://coma.design/project/nai-publishers/architectural-laboratories-greg-lynn-and-hani-rashid, 2000.

surface rippled in response to passing pedestrians – an effect that was easy enough to simulate on the computer screen, but which constituted a considerable challenge in terms of actual fabrication (Goulthorpe, 2002). Although the project in Birmingham was not constructed, Goulthorpe teamed up with Mark Burry, then a professor at Deakin University, Australia, along with his colleagues, Saeid Nahavandi and Abbas Kouzani, to try to realise the project. Burry and his team suggested a forest of pistons that was able to actuate the panels of the surface of the wall to the point that words could even be *imprinted* on it.

Another centre was the Bartlett School of Architecture, University College London, whose early graduates include Usman Haque and Jason Bruges. This work was promoted by publications such as Lucy Bullivant's *4dsocial: Interactive Design Environments* (2005) and *4space: Interactive Architecture* (2007). The legacy of this tradition can be found in the new MArch program at the Bartlett School of Architecture, Design for Performance and Interaction.[5] By the late 2000s it was clear that a new technologically advanced understanding of the potential of interactive architecture had arrived, and these developments were consolidated by more reliable interactive projects and a series of authoritative texts on interactive design, especially Michael Fox's highly influential *Interactive Architecture* (2009), produced with the assistance of Miles Kemp, and his follow up book, Interactive Design: Adaptive World (Fox, 2016).

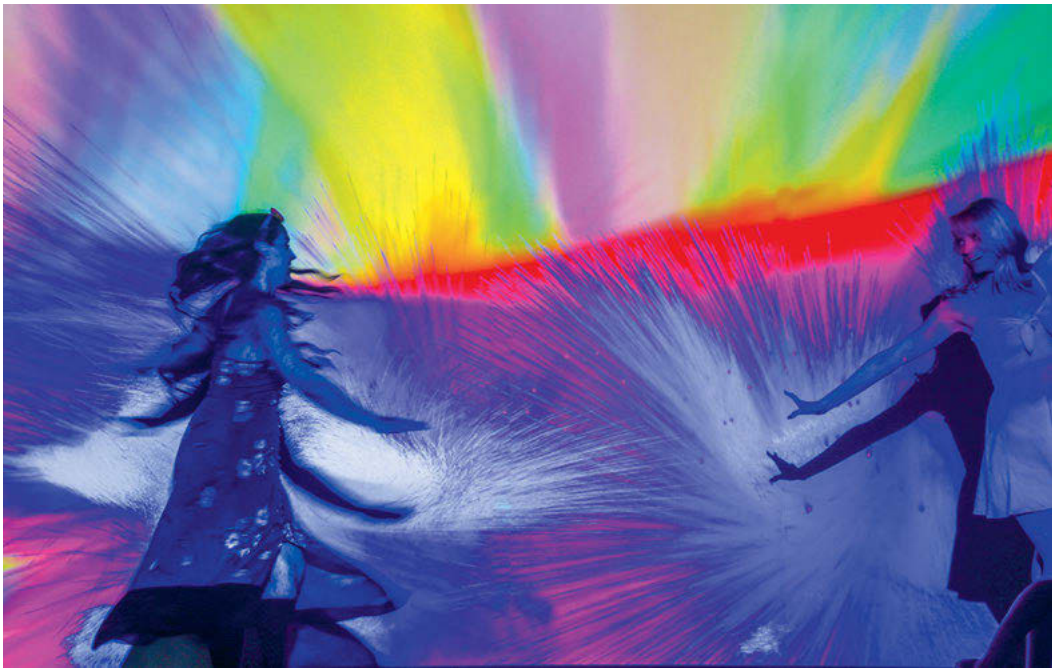
In recent years a number of architects, including Philip Beesley, Michael Fox, Usman Haque, Omar Khan and Ruairi Glynn – whose work is featured in this volume – have been working in this territory and taking interactive design to a new level. For most of them, their interest in interactive architecture has shifted away from merely pragmatic factors such as the changing needs of users, energy efficiency, and so on (these are issues mainly addressed in smart environments). Nowadays, as Fox argues, the primary motivation behind developing interactive dynamic spaces is to explore the implementation of new technologies on human patterns of interaction (Fox & Kemp, 2009).

The Future

It is clear that interactive and responsive approaches to design are here to stay, from simple responsive systems, such as learning from users to activate lighting/ventilation systems that preserve energy, through to more advanced bodily interaction. These systems engage with human behaviours through novel material interfaces which push the boundaries of computationally enhanced environments.

Moreover, interactive design has become one of the fastest developing areas of computational design in recent years, thanks largely to the commercial availability of various devices to either sense human operations or control a response to those operations. Sensors, such as body tracking and hand tracking cameras (e.g. facial tracking, body tracking and hand tracking cameras such as Kinect and Leap Motion), have become common, while micro-control boards (e.g. Arduino, Raspberry Pi, and Galileo by Intel) and actuators (e.g. servos, DC motors, stepper motors, smart materials, and pneumatic devices) have also become highly popular. If we add the increasing availability of cheap and readily available lighting systems, such as RGB LED lights in various forms, addressable LED strips and other similar products, we can see that a whole new field of research and

5 Design for Performance and Interaction, UCL. Accessed from: https://www.ucl.ac.uk/bartlett/architecture/programmes/postgraduate/march-design-for-performance-and-interaction



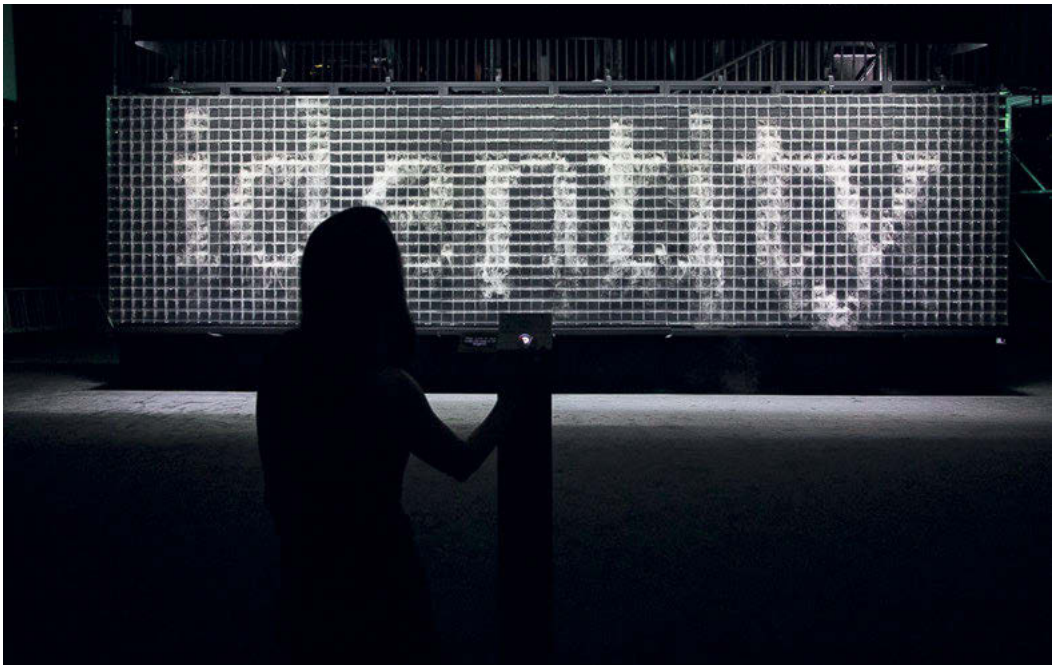


Fig. 7 Body paint by Memo Akten, 2017. Interactive Media enables participants to paint on a virtual canvas with their body, interpreting movement and gestures into evolving compositions.

Fig. 8 Cloud Display by Rafael Lozano-Hemme, 2016. Cloud Display is a vertical water fountain consisting of 1,600 ultrasonic atomizers, controlled by a machine-learning voice recognition system. When a participant speaks into an intercom, the piece writes any words or sentences spoken using wisps of pure water vapour. The words appear and disappear slowly, forming an evocative and temporary display of language.

development has opened up, such that any student of architecture and design can now experiment with these systems. Indeed, instruction about these systems arguably should be offered in every school of architecture, although it might take some time before expertise in working with these systems has spread from early centres of interactive research, such as the Interaction Design Institute Ivrea,[6] to less technologically advanced educational environments.

A Short Critical Reflection

With the increasing availability of technologies for sensing and actuating, the creative community has access to a spectrum of design techniques which were not available before. These technologies have expanded the range of design options, and have injected more control, customisation and flexibility into the design process.

While the creative community is collectively exploring this new space of opportunity, we should also reflect on the social, political and psychological implications of these systems. It is necessary to adopt a critical stance towards the use of these technologies. As such issues such as *surveillance* and *privacy* become crucial, as many interactive technologies are able to see, track and monitor our activities and have the potential to control our behaviours. If we were to discover networked sensors embedded in the built environment, for example, sensing and recording us, it might cause us to feel uncomfortable. Instead of having every device networked together ubiquitously — as was originally envisioned with the Internet of Things (IoT) — Alex Pentland, Professor of Media Arts and Sciences at MIT Media Lab, proposes the idea of *local/perceptual intelligence*:

> "Such ubiquitous networking and its attendant capacity to concentrate information has too close a resemblance to George Orwell's dark vision of a government that controls your every move. Instead, I propose that local intelligences … and mainly perceptual intelligence … combined with relatively sparse, user-initiated networking can provide most of the benefits of ubiquitous networking, while at the same time making it more difficult for outsiders to track and analyse user's behaviour" (1999).

Instead of avoiding these technologies altogether, because of their potentially exploitative and manipulative use, we should differentiate between the *tool* itself and its application. A knife, for example, could either be a murder weapon or a tool for cutting an apple. We should therefore ask in *what context*, *why* and *how* the data is captured and used. It is important to stress that in interactive design, no data should be collected and stored centrally which might compromise a user's privacy at the expense of a central governing system.

Structure of the Book

This book is divided into four different sections, with each section including a series of theoretical articles followed by projects developed by practitioners in the field.

The first section, "From Cybernetics to Interactive Design", traces the emergence of interactive design and architecture out of the field of cybernetics, highlighting the influence of cyberneticians such as Gordon Pask on early interactive designers such as John Frazer — who collaborated with Pask — and on later designers such as Usman Haque who were inspired by Pask. This section also

6 Interaction Design Institute Ivrea. Accessed from https://interactionivrea.org/en/index.asp

includes some theoretical reflections on interactivity by Neil Leach.

The second section, “A New Kind of Interaction”, addresses emerging models on interactivity ranging from the scale of wearables to architecture through a series of articles and projects. It begins with a theoretical article by leading interactive architect and designer Philip Beesley calling for a new model for interaction. This is followed by articles exploring the world of affective computing by Behnaz Farahi and Mona Ghandi. This section also engages with embodied interaction and includes an article by Elyne Legarnisson addressing how the body has become the crucial site of interaction within the computationally enhanced environment.

The third section, “Material Interactivities”, engages with the theme of new material behaviours and explores how materials should be allowed to be active, dynamic, and shape changing, so they can serve as programmable interactive interfaces. “Material Interactivities” begins with an interview with Skylar Tibbits, one of the pioneers of active programmable matter. Yasuaki Kakehi’s article describes some novel material interfaces used for art installations. The article by Lining Yao and Harshika Jain addresses morphing matter as an intricate interplay of relationship between geometry and internal forces. This section finishes with an article by Manuel Kretzer, where he reflects on the larger question of the future where experimentation with materials and design play a crucial role in design and architecture practices.

The last section, “Transdisciplinary Approaches”, addresses the importance of a transdisciplinary approach towards interactive design and sheds some light on alternative design methodologies.

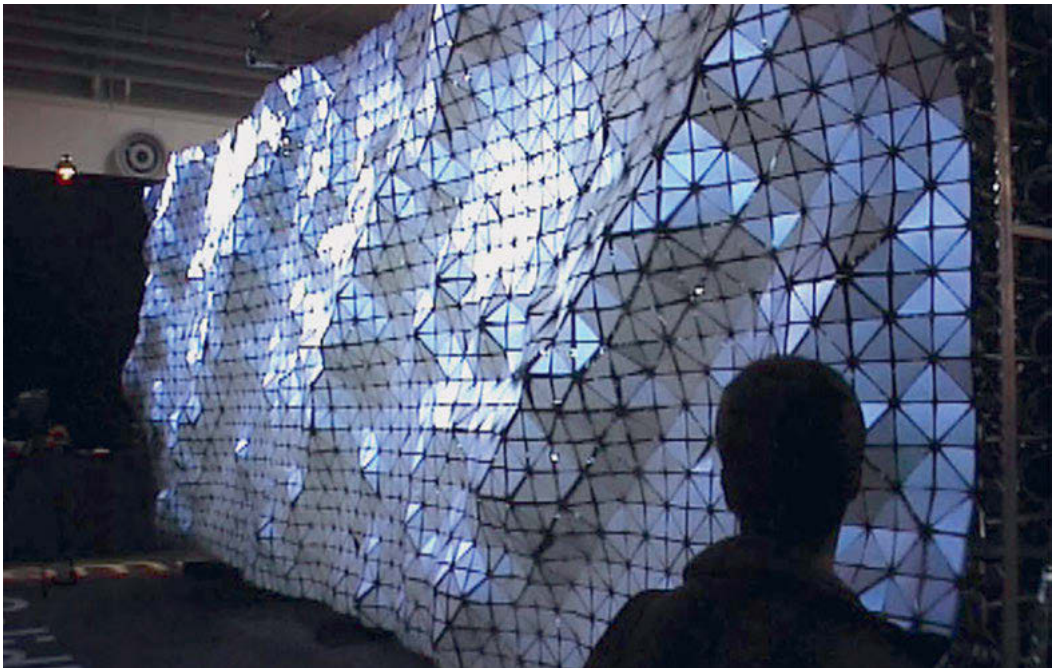


Fig. 9 HypoSurface by Mark Goulthorpe. The intention was to build the world’s first display system where the screen physically moves.

In this section, articles by Guvenc Ozel (Ozel Office) and Ruairi Glynn (director of Interactive Architecture Lab at UCL Bartlett) both argue for a transdisciplinary approach where boundaries between disciplinary practices become blurred. Finally, in his article Michael Fox describes how some of the challenges in dealing with the highly technology-intensive nature of these types of work in architectural studios could be addressed.

BIBLIOGRAPHY

BANHAM, REYNER. *The Architecture of the Well-Tempered* Environment. University of Chicago Press, 1969.

BULLIVANT, LUCY, editor. 4dsocial: Interactive Design Environments. 1 edition, Academy Press, 2007.

BULLIVANT, LUCY, editor. 4dspace: Interactive Architecture. 1st edition, Academy Press, 2005.

CHALK, WARREN. "Living 1990: Archigram Group". Polished in *Architectural Design*, Vol. 69 (1-2): iv-v, Originally published in March 1967 issue of Architectural Design, 1967.

CIPOLLA, ROBERTO, and ALEX PENTLAND, eds. *Computer Vision for Human-Machine Interaction*. 1 edition. Cambridge ; New York: Cambridge University Press, 1998.

DUBBERLY, HUGH, and PAUL PANGARO. "How cybernetics connects computing, counterculture, and design". Walker Art Center, *Hippie Modernism: The Struggle for Utopia*, Exhibition Catalog, 2015.

FOX, MICHAEL, editor. Interactive Architecture: Adaptive World. Princeton Architectural Press, 2016.

FOX, MICHAEL, and MILES KEMP. Interactive Architecture. 1 edition, Princeton Architectural Press, 2009.

FRAZER, JOHN. *An Evolutionary Architecture*. London: Architectural Association Publications, 1995.

GOULTHORPE, MARK. 'Smectic State', in Neil Leach, *Designing for a Digital World*, London: Wiley, 2002, pp. 101-107

HAQUE, USMAN. "Architecture, interaction, systems". In *AU: Arquitetura & Urbanismo,* Vol. 149: 1-5, 2006.

LEACH, NEIL. *Architecture in the Age of Artificial Intelligence: An Introduction to AI for Architects*. Bloomsbury, 2022.

OOSTERHUIS, KAS. *Architecture Goes Wild*. 010 Publishers, 2002.

PASK, GORDON. "The Architectural Relevance of Cybernetics", *Architectural Design*, September issue No 7/6, John Wiley & Sons Ltd (London), 1969, p. 494-6. ©John Wiley & Sons Ltd.

PIAS, CLAUS, editor. *Cybernetics: The Macy Conferences 1946-1953. The Complete Transactions*. University of Chicago Press, 2016.

PICKERING, ANDREW. *The Cybernetic Brain: Sketches of Another Future*. Chicago; London: University Of Chicago Press, 2011.

PICKERING, ANDREW. "Living In The Material World" In Mitev, Nathalie, and Francois-Xavier de Vaujany (eds.) *Materiality and Space: Organizations, Artefacts and Practices*. Houndmills, Basingstoke, Hampshire ; New York, NY: Palgrave Macmillan, 2012.

SCHUMACHER, PATRIK; 'Robotic Fields: Spatialising the Dynamics of Corporate Organisation', in Neil Leach, *Designing for a Digital World*, London: Wiley, 2002, pp. 108–115

SPUYBROEK, LARS. *Nox: Machining Architecture*. London: Thames and Hudson, 2004.

VON FOERSTER, HEINZ. *Understanding: Essays on Cybernetics and Cognition*. 2003 edition. New York: Springer, 2002.

WIENER, NORBERT. Cybernetics or Control and Communication in the Animal and the Machine. Cambridge, MA: MIT Press, 1948.

YIANNOUDES, SOCRATES. *Architecture and Adaptation: From Cybernetics to Tangible Computing*. Reprint edition, Routledge, 2016.

Part I:

From Cybernetics to Interactive Design