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Modulating Territories, Penetrating Boundaries

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Introduction

Commissioned by Festo, the InteractiveWall[1] is an architectural-scale installation work developed for presentation at the Hannover Messe 2009, the world's leading showcase for industrial technology [fig. 1]. The InteractiveWall was a collaboration between Festo, Burkhardt Leitner constructiv, and Hyperbody,[2] as part of the Festo Bionic Learning Network.[3] (See Acknowledgements for a listing of participants and contributors).

Participation in the InteractiveWall project provided Hyperbody with an opportunity to develop an interactive architectural component that transforms the wall from a static backdrop to a key part of a dynamic customisable environment. For Hyperbody the motivation for the development of interactive architecture is a response to the rise in demand of programmable, multi-mediated, and customisable environmental conditions in the digital age. As the paradigm shifts in the international architectural discourse towards the integration of new technologies, materials and performance, investigations into interactive architecture will help transform and revolutionise our social life in the domestic built environment. Inventing entirely new ways of using and designing space incites us to explore new ways of embodying user participation and locality. One of the most effective ways to seek out this exploration is through the development of installations that allow researchers to isolate and explore problems effectively in interactive architectural design.

Related Works

The compelling works of Aegis Hyposurface[4] by dECOi, and Party Wall[5] by nArchitects help illustrate the context in which the concept of interactive walls has been previously explored. Although quite different in their aims and accomplishments, these projects transform and redefine the traditionally understood connotation and transforming identity of a wall when it becomes interactive: passive becomes active, determined becomes indeterminate, material becomes immaterial, permanence becomes temporal, barrier becomes transfuse, and boundary becomes borderless.

Aegis Hyposurface was built upon a framework of pneumatic pistons, springs, and metal plates, all of which were used to deform a programmable façade-like surface.[6] This sensitive wall interacts spatially with its environment by moving its interlocking flexible panels in synchrony in response to various stimuli from the surrounding environment. Projects such as the Hyposurface help explore the impact on participants when encountering a dynamic full-scale architectonic building object. According to the testimony of the project creators, participants experienced the movements of the Hyposurface with a great deal of curiosity and awe.

Just like Aegis Hyposurface, Party Wall manipulates the quality of the space, by creating a variable boundary of an exhibition. In reaction to the presence of participants, the Party Wall dynamically modulates its territorial and spatial qualities by moving portions of horizontal strips of foam that make up the wall. Because the wall is a permeable membrane, visitors on either side are enabled to engage in a reciprocal relationship. As a result of this mediation between changing conditions the wall governs interaction between the participants.

Like the InteractiveWall, each of these works reflects fluctuations within the environment that surround it and alters its expression in response to these changes. However, the varying qualities of movement when comparing these works with the InteractiveWall underscore their difference, for each new method of actuation results in a unique experience of the architectonic object. Also, unlike these works, the InteractiveWall did not confine its behavioural expression to the modality of movement. Rather, the capacity of the InteractiveWall to serve as an interactive structure is also reliant on the expression of state through the combined modalities of movement, light, and sound.[7]

Technical Description

The InteractiveWall is composed of 7 wall components measuring 1.09 meters wide, 0.53 meters deep, and 5.30 meters tall. The basic composition of each element is a frame structure covered by an elastic fabric skin. Contained within each element are all the motors, sensors, lighting, loudspeakers, and interfacing needed to make the element operate. Therefore each element can be considered a self-contained system. Thus the InteractiveWall is a modular system, whereby elements can be readily added or removed, change location, and arranged in any order [fig. 2].

Each element of the InteractiveWall can move independently in a fluid-like fashion under computer control. The kinetic behaviour of the InteractiveWall is based on a proprietary technology used in Festo's factory automation known as the Fin Ray Effect, developed by Leif Kniese of EvoLogics.[8] Derived from the functional anatomy of a fish's fin, the Fin Ray structure consists of two alternating tension and pressure sides flexibly connected by rigid ribs. When one of the flexible sides is subjected to pressure the Fin Ray structure bends in the direction opposed to the force applied, exhibiting a high degree of movement with minimal effort. In the InteractiveWall, each element is composed of longer flexible supports (made out of a carbon-composite material) and stiff interior supports (made from aluminium tubing). Pushing or pulling near its base will lengthen one side of a Fin Ray element, causing the structure to curve toward the direction force. In the InteractiveWall element the shape of a Fin Ray element is controlled using a pair of DNCE-32-400 electronic cylinders, driven by EMMS-40-M-TMB servo motors (provided by Festo AG & Co. KG), which pushes and pulls on one side of the wall element in order to dynamically achieve a desired form.Within each wall element is a Festo CMMP-AS motor controller, which directly controls the position of the servo motors (and thereby the pistons). In order to unify the communications and control, Hyperbody interfaced with the CMMP-AS using custom circuitry built around Arduino,[9] an open-source electronics prototyping platform [fig. 3].

In addition to proving an interface to the Festo hardware, the custom circuitry was designed to control lights and read sensor data in each InteractiveWall element. Each element has 48 channels of LED light control. The lights are embedded behind the skin, with 24 channels of LED light distributed non-linearly on each side. The distribution of the 48 light channels was made possible via an *LED Painter* circuit based on the TLC5940 IC PWM driver, sold off-the-shelf by Brilldea.[10]

For sensing, MaxBotix *MaxSonar*[11] motion sensors capable of detecting distance were employed. Each InteractiveWall element has two sensors, one for each side. In the software, sensors were combined to create an image of the sensor space, which was used to interpret user presence around the InteractiveWall.

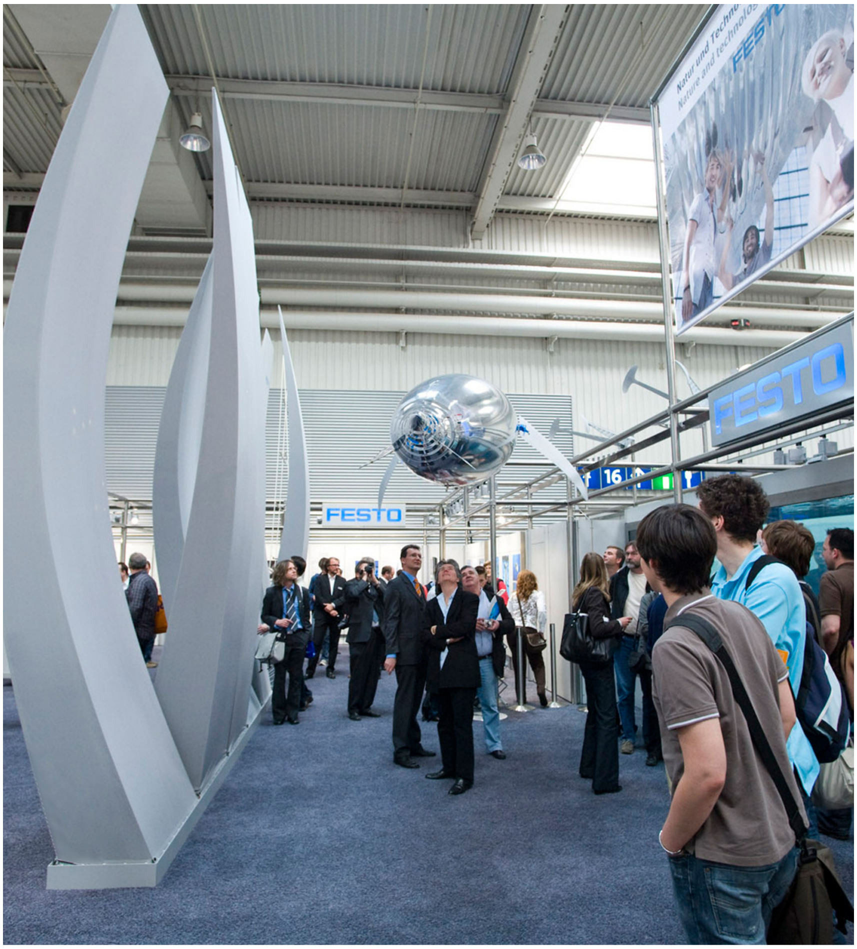

Fig. 1

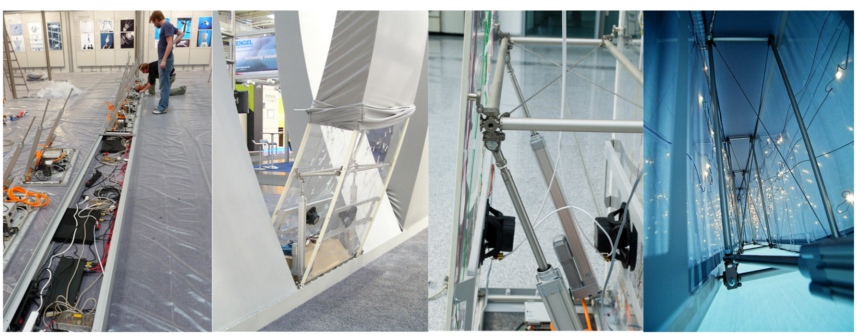

Fig. 2

Fig. 1: The InteractiveWall at the Hannover Messe. Copyright Festo AG & Co. KG, photos Walter Fogel.
Fig. 2: The exposed frame of the InteractiveWall, showing the interior pistons and electronics infrastructure. Copyright [Hyperbody and] Festo AG & Co. KG, photos Walter Fogel

Sound production in the InteractiveWall was developed using a software package called Ableton Live.[12] Each InteractiveWall element has an independent audio channel distributed by a multichannel audio interface, embedded in the base of the composite of InteractiveWall elements.

The central point of the various modalities of the InteractiveWall elements was a custom-control software, designed in a software development toolkit called Max/MSP/Jitter.[13] Through the interface the various systems of the InteractiveWall could be monitored, sensors could be calibrated and filtered, and the behaviour of the system could be controlled [fig. 4].

Behaviour

As a multimodal interactive system the InteractiveWall consists of a layering of the modalities of movement, light, and sound. The development of the general behaviour of the InteractiveWall was inspired by the phenomenon of emergent synchrony as described in the book *Sync: the Emerging Science of Spontaneous Order* by Steven Strogatz[14] and in his talk on TED, *Why things sync up*.[15] According to Strogatz, spontaneous synchronous order (which Strogratz describes as *sync*) is an observable characteristic found throughout nature in systems ranging from physical phenomenon to complex social behaviours. In his talk on TED, Strogatz asserts that the phenomenon of *sync* is guided by a simple set of four rules:

1. Individual elements are only aware of their nearest neighbours.
2. The elements have a tendency to line-up in relation to each other.
3. While the elements follow each other, they are attracted at a distance (either a spatial distance, a time distance, or both).
4. Response to stimulus. The agents in a sync system respond as a single entity, rather than as individuals, when their swarm structure is disrupted (for example when attacked by a predator).

One way Strogatz illustrates the phenomenon of *sync* in his book is through the behaviour of the firefly. Fireflies have a tendency to synchronise their flashing tails whenever they are near each other. Through the cumulative effect of their flashing tails complex patterns emerge out of a simple localised behaviour of emergent sync. Although they are fairly simple animals, the fireflies are incredibly able to maintain this sync behaviour even when they are swarming by the thousands.

The behaviour of the InteractiveWall can be described in terms of the four rules of sync, as described above. While the primary synchronous behaviour of the firefly is flashing light, the baseline behaviour of the InteractiveWall is expressed in movement, as illustrated in Figure 5. As shown in step 1, in its resting state the 7 InteractiveWall elements are aligned in a row on the showroom floor of an exhibition. Step 2 illustrates how approaching participants disrupt the InteractiveWall elements, which react to the participants by bending away from them in response to their presence. The bending behaviour is a local response, with each element bending independently based on the distance of the participant from the node. The elements of the InteractiveWall bend independently of neighbouring elements in response to the presence of a participant. Although responsively independent, the InteractiveWall elements also synchronise by constantly readjusting their positions in order to align with the position of their nearest neighbours. The synchronous behaviour between the elements of the InteractiveWall conflicts directly with the asynchronous behaviour produced by the response to a participant. The result is a series of complex wave patterns that propagate through the InteractiveWall as a whole; this is illustrated in the three phases of step 3. If the wall is left alone it will ultimately come to a resting state as shown in step 3c.

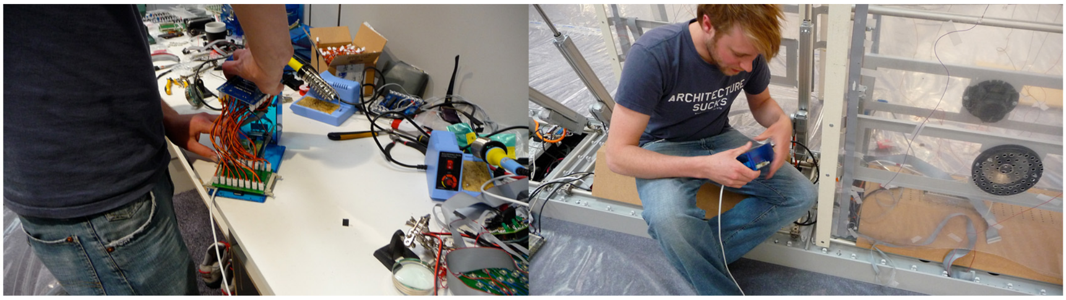

Fig. 3

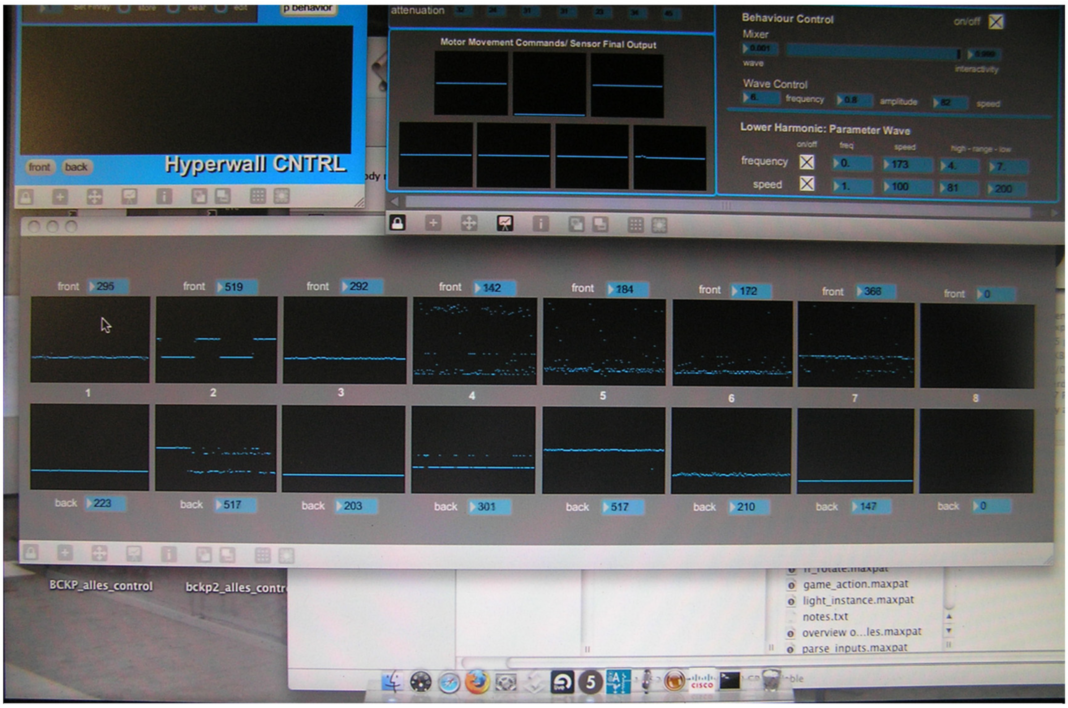

Fig. 4

Fig. 5. 1. 2. 3a. 3b. 3c.

Fig. 3: Assembly of one of the Arduino-based control boxes developed for each InteractiveWall element.
Fig. 4: The custom control software for the InteractiveWall, running on a MacBook Pro during the set-up for the exhibition at the Hannover Messe.
Fig. 5: 1.The seven elements of the InteractiveWall; 2.Participants approach the wall, stimulating movement in the wall elements; 3.Cumulative wave patterns emerge in the body of the wall, resulting from inter-element synchronous behaviour conflicting with the asynchronous input.

To express the modality of light, the skin of each component of the InteractiveWall is covered by a unique, irregular distribution of dynamically controlled LEDs [fig. 6]. The LED skin changes in response to the motion of the body of the InteractiveWall component by forming more agitated patterns when a component is moving outwards, and more tranquil patterns when the element is centred. The sum of the behaviour unfolding on LEDs on the individual InteractiveWall components forms an emergent, highly reactive pattern of light that glides across the body of the InteractiveWall as a whole.

As with the light and movement patterns, the modality of sound expresses the localised condition of an InteractiveWall component. In this case sound changes state as an expression of the local sync of a particular InteractiveWall component in relation to its neighbouring components. The amount of sync is determined via a ratio based on the alignment of an individual component in relation to its neighbours. Moments of synchronicity are represented by calmer, lower pitched sounds, while asynchronous behaviour results in more intense sound. The propagation of the sound from high to low intensity is varied throughout the InteractiveWall, transforming each node into a member of a choir that sings the composite state of the InteractiveWall as a complex pattern of oscillating chords.

As described above, users interact with the InteractiveWall by perturbing the synchronous qualities of the InteractiveWall. Via the sonar sensors embedded in the wall, both sides of the InteractiveWall are responsive to approaching participants. Therefore, the InteractiveWall often must negotiate between two participants standing on both sides of a component simultaneously. The InteractiveWall resolves this situation by favouring the participant who is closest to the wall and responding only to that participant. This gives rise to an emergent game-like quality in the InteractiveWall components [fig. 7]. The InteractiveWall has a tendency to move away from the participant closest to a component. As a result the closest participant is rewarded by the component by being sheltered by the arc of the component's curved form. Meanwhile the participant furthest away from a component becomes even more repelled, because the component is pushing them farther away from the structure.

Although connected, the physical movements of InteractiveWall components, the light patterns, and the sound behaviour change independently, reacting at varying rates, expressing the qualities of the InteractiveWall's behaviour in a unique manner. The combination of these components contributes to the living system as scaled and modulated expressions of the synchronous and game-like systems described above.

Results & Evaluation

The primary goal of the development of the InteractiveWall was to develop a compelling exhibit for Festo at the Hannover Messe. However, Hyperbody attempted to seize this opportunity to also evaluate the impact and performance of the work. In order to investigate the performance of the InteractiveWall the public interactions with the prototype during the Hannover Messe were recorded. The direct observation and analysis of recorded video provided a general starting point for understanding of how participants approach and interact with the installation. But, because of the formal circumstances of Hannover Messe it was not possible to execute any user-based surveys, so evaluations were based on subjective observation alone.

Besides the formal limitations and our lack of user-based surveys, other factors confounded our results mostly due to the large number of visitors coming to see the exhibit in the Festo booth. Specifically the high rate of visitors and the other activities happening in the Festo booth made it difficult to recognise the direct impact of the InteractiveWall on the participants, specifically who was willing to

Fig. 6a b

Fig. 7

Fig. 6: a.Front view of the InteractiveWall (long shutter speed). b.The InteractiveWall by night, showing the irregular distribution of lights on the skin. Copyright Festo AG & Co. KG, photos Walter Fogel.
Fig. 7: The responsive behaviour of the InteractiveWall leads to active participant engagement. Copyright Festo AG & Co. KG, photos Walter Fogel.

'play', and who wasn't; and whether or not a participant could recognise another user's involvement in the 'play' of the work.

Despite these complications, there were moments of slower activity and clear engagement on behalf of visitors' participation with the InteractiveWall. Finally, the context of the Messe provided some insight into how well such a system performs in a somewhat real-world environment, full of distractions and other participants, and context could not be readily controlled.

Through these observations some initial comments can be made about the impact of the work (at least in this context) and some potential areas for future improvements. As might be expected, many participants seem clearly drawn to the 1-to-1 layers of interaction in the system. We gather this because the movement was difficult to interpret; many participants were initially drawn to the light, after which they might recognise interactivity in the movement, assuming that other participants were not disturbing the InteractiveWall from the other side. Also, participants seemed (logically) more engaged with the work during quieter moments of the exhibition. Due to the high volume of visitors and surrounding exhibitions, the sound was often difficult to hear as well. But in quieter moments participants were able to hear the sounds and experience all of the modalities of the work. This, in correlation with the increased engagement of the user, could be seen as an indication of the increased interest of the participants when they experienced of all of the modalities of the work.

Applicability

The Dynamic Sound Barrier-project proposal by our partner from practice, ONL [Oosterhuis_Lénárd],[16] came forth as an ambitious and groundbreaking initiative to extrapolate the technology employed by the InteractiveWall and apply it within the real world of design and construction. Working within the boundaries to stylise and optimise a building form for maximum noise reduction and aesthetics, the Dynamic Sound Barrier shows that applied technology can liberate architectural form in a way that makes it more efficient and viable.

Inspiration for the development of the Dynamic Sound Barrier rose out of the desire to mediate between the conflicting needs addressed by conventional acoustic barriers to limit the intrusion of high-noise pollutants, such as train tracks and large highways, while eliminating the resulting fragmented territory created by the introduction of the barrier in its context. As a dynamic structure the Dynamic Sound Barrier mediates between the conflicting programs of noise reduction and open territory by modulating between two states. When no trains are nearby, the Dynamic Sound Barrier lies in a resting state, close to the ground, exposing the landscape around it. When a train approaches the Dynamic Sound Barrier comes alive by standing erect, obscuring the noise from the train, while only momentarily obscuring the landscape around it [fig. 8].

Like the InteractiveWall, the Dynamic Sound Barrier is composed of a population of architectural components that are given a dynamic behaviour in real time. Like in the InteractiveWall, the combination of sensors and actuators embedded in the proposed structure would enable the components to interact with surrounding components in a self-organised manner. The design strategy of the employment of dynamic components provides for a high standard of flexibility for the design. Each component is adaptable and responds in accordance with the noise-cancellation and aesthetic requirements. The construct becomes a lean and flexible barrier that only rises when its noise-nuisance function requires it, while the elegant movement of the Dynamic Sound Barrier exhibits unique and compelling architectural qualities. Therefore, in addition to functional noise reduction, the Dynamic Sound Barrier

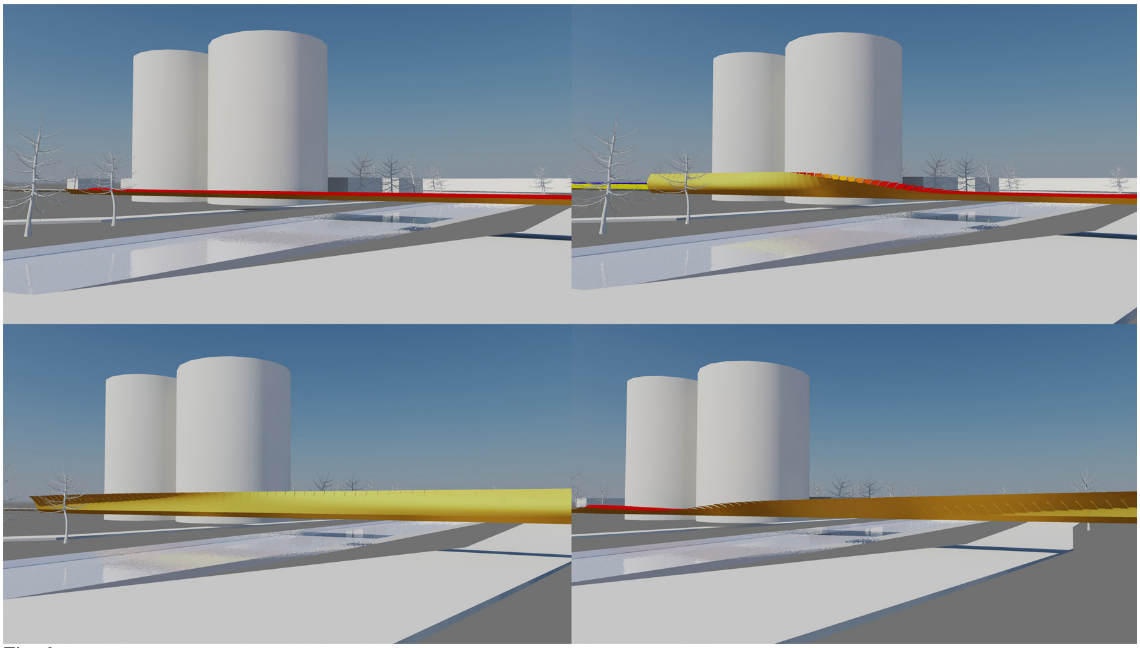

Fig. 8a

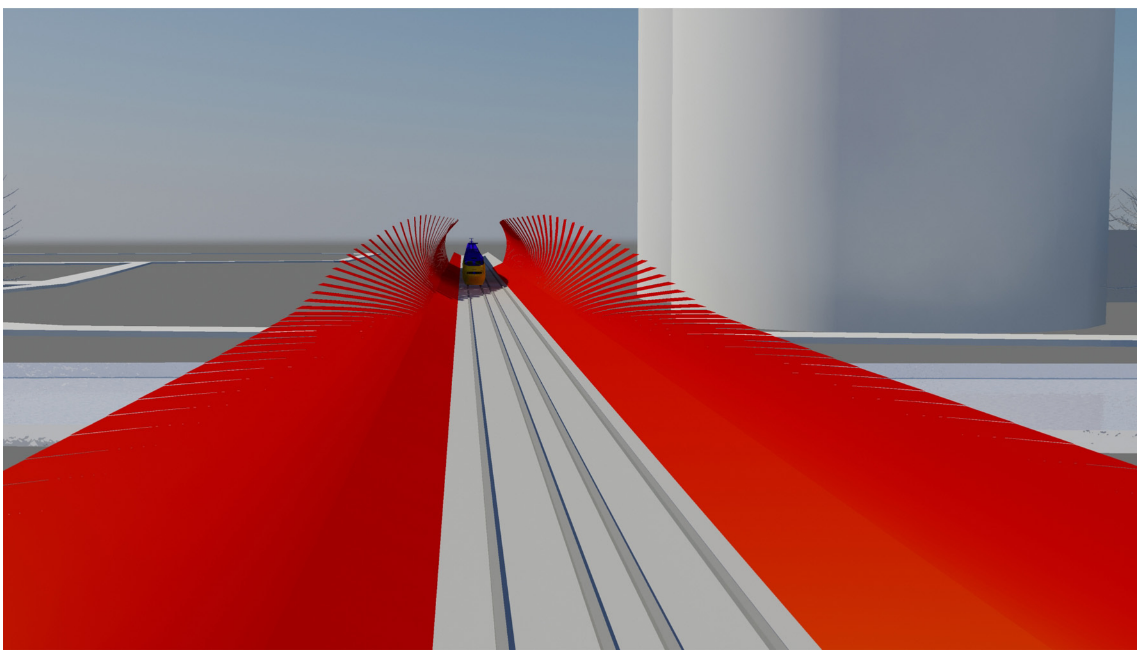

Fig. 8b

Fig. 8: a. the Dynamic Sound Barrier reconfiguring itself to cover the noise from the flow of passing traffic; b. The Dynamic Sound Barrier comes alive by standing erect, obscuring the noise from the train. Renderings ONL [Oosterhuis_Lénárd.

provides an aesthetic addition to the natural environment as well.

The proliferation of emerging interactive architectural projects in the urban environment, such as the Dynamic Sound Barrier, results in a transformation of the built environment.[17] The implied cultural implementations will challenge architecture's traditional identity revolutionising and reinventing our social spaces from static to dynamic.[18] In opposition to traditional architecture the design essence of interactive architectural objects lies not only in their physicality, but also in their behaviour, as both are deeply intertwined. As Michael Fox and Milles Kemp acknowledge in their recent publication Interactive Architecture: '[…] we may no longer ask "What is that building?," or "How was it made?," but rather, "What does that building do?"'.[19]

In order to create successful architectural spaces of this kind, the architectural discipline should not merely focus on designing spatial and behavioural expressions. There is a growing need for guidelines for developing and building spaces and objects capable of dynamic and interactive architectural performance. As the Dynamic Sound Barrier project illustrates, a noise ordinance in the Dutch technical building regulations[20] demands for calculations for peak decibel levels to determine the noise pollution. This is a serious bottleneck in the implementation of a dynamic acoustic structure that only rises when its noise-cancellation properties are required.

Although many government authorities have been working in a 'performance-based building' regulatory environment as a means of improving innovation in building and construction industry,[21] to this date specifications, prescriptive codes, regulations and standards are not currently adaptable to the evaluation of dynamic building objects. In order to better serve dynamic architectural innovations, the view of architectural 'performance' should be expanded and embrace the renewed engagement with architecture as a performing body that establishes relationships between environment and participant.[22] A creative approach to responding to the current requirements related to legislation on building design provides designers a fresh opportunity for reformulating and imposing new regulations. In leading the conception and implementation of the new legislation, researchers and practitioners should play an active role, as this role for 'designing' legislation is as much a design task as any other. If experts in interactive architecture do not take on this task, it is doubtful that non-experts in the planning community will.

Conclusion

The InteractiveWall and Dynamic Sound Barrier help illustrate, in a very literal sense, the definition of penetrating boundaries and modulating territories. In addition, these projects demonstrate a process whereby interactive architectural explorations could be brought to the next level, and start addressing how they can be implemented in real-world contexts. As architecture becomes responsive and interactive, participants can influence its behaviour. In this sense architecture follows a general development in society towards participation, personalisation and customisation, which follows the evolution of contemporary mundane technologies. While much focus in the discourse of interactive architecture has been on experimentation through installations, it is perhaps time to start evaluating these experiments and translating them into real-world projects that will better meet future societal needs.

To design a territory that is changing and adaptive is to design an architecture that is interactive, spontaneous and alive. This is a notion closely linked to Gordon Pask's envisioned perception of architecture as dynamic systems consisting of both buildings and their inhabitants. As Gordon Pask writes: 'Architects are required to design dynamic rather than static entities. Clearly the human part of the system is dynamic. But it is equally true that the structural part must be imagined as continually regulating its human inhabitants'.[23] In this architectural paradigm new design methods and concepts lead to changes in the design process and the role of the architect. As Kas Oosterhuis puts it, 'The architect in society today is a well-trained hyperconscious idiot savant. Today's architect is an information architect, able to act intuitively and to process rationally at the same time'.[24]

While the characteristics of the InteractiveWall and Dynamic Sound Barrier are similar, they have very different aims. The InteractiveWall exhibits a particularly emotive quality that engages participants in a game-like play. On the other hand, the Dynamic Sound Barrier transforms what would otherwise be a static boundary into a living landscape, reconfiguring itself to cover the noise from the flow of passing traffic while avoiding being a static barrier that permanently pollutes the horizon. These differences underscore the flexibility of interactive architectural design in changing contexts.

Festo's commission to develop the interactive design for the InteractiveWall presented at the Hannover Messe industrial trade-fair provided Hyperbody with an architectural-scale prototype for the exploration of interactive architecture. Although the phase of the project described in this article has come to an end, with the full support from Festo, the development on the InteractiveWall will continue. In particular, Hyperbody is planning to continue exhibiting the current version of the wall at different events and making improvements along the way. In doing so, we gain invaluable knowledge on how to develop optimised systems, cascading these improvements to future projects and speeding up future developments. Among the improvements considered will be better sensing and actuating technologies, alternative spatial arrangements and form factors, high resolution flexible displays, and the implementation of embedded distributed computing systems.

Acknowledgements

InteractiveWall copyright Festo AG & Co. KG, photos Walter Fogel. Dynamic Acoustic Barrier, Breda 2009, architect ONL (Oosterhuis_Lénárd) bv Rotterdam, rendering by ONL (Oosterhuis_Lénárd) bv. InteractiveWall has been awarded the GOOD DESIGN™ Award 2009.

Project initiator: Dr. Wilfried Stoll, Chairman of the Supervisory Board, Festo AG.

Project managers: Professor Kas Oosterhuis, Chris Kievid, Bernard Sommer, Hyperbody, Faculty of Architecture, Delft University of Technology, The Netherlands.; Michael Daubner, Andreas Dober, Burkhardt Leitner constructiv, Stuttgart, Germany; Markus Fischer, Festo AG & Co. KG, Ostfildern, Germany.

Project team: MarkDavid Hosale, Remko Siemerink, Vera Laszlo, Dieter Vandoren, Hyperbody, Faculty of Architecture, Delft University of Technology, The Netherlands; Robert Glanz, Domenico Farina, Burkhardt Leitner constructiv, Stuttgart, Germany; Gerhard Bettinger, Roland Grau, Uwe Neuhoff, Festo AG & Co. KG, Ostfildern, Germany.

Notes

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2. Hyperbody is a contemporary information-technology driven research and design group at the Faculty of Architecture at the Delft University of Technology directed by prof. ir. Kas Oosterhuis. Hyperbody is at the forefront of developing novel, alternative forms of engineered architectural, interactive and urban scape.
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Biographies

Dr. MarkDavid Hosale is a media artist and composer with a PhD in Media Arts and Technology from the University of California in Santa Barbara (2008). As an interdisciplinary artist and composer MarkDavid has found that, beyond the common language of new media, the connecting tissue between various art practices and music can be found in narrative - in particular, the kind of narrative that is structured using nonlinear representations of information, time, and space. Nonlinear narrative is an inherent aspect of new media that provides a common baseline whereby media artworks can be evaluated and understood. In addition to non-linear narrative, MarkDavid's interdisciplinary interest in art and music comes from the exploration of the connection between the physical and the virtual world. Whether as part of an installation work or performance work, the virtual spaces he creates are technologically transparent, sophisticated and virtuosic, as well as intuitive to experience and use.

Chris Kievid is a researcher at Hyperbody, a contemporary information-technology driven research and design group at the Faculty of Architecture of the Technical University in Delft. He graduated *cum laude* in architecture at the TU Delft in 2006. His thesis received a nomination for the Dutch Archiprix 2007. As a freelance architect and interaction designer he has worked for the multidisciplinary design office ONL [Oosterhuis_Lénárd] on a variety of innovative projects. As a researcher and project manager at Hyperbody he has been responsible for the development of the design environment for immediate design and engineering: protoSPACE, the project iLite for the travelling road show Philips Transitions II and the InteractiveWall installation for the Hannover Messe. As a coordinator and tutor he is involved with the Hyperbody educational MSc 2 and minor program.