Real-time Responsive Spatial Systems: *Design Driven Research Experiments in Interactive Architecture*

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The design-research experiments developed by Hyperbody, TU Delft, Faculty of Architecture, focus on the domain of Interaction design from a spatial perspective. These interactive spaces demonstrate a fusion between the material, electronic and digital domains, which interface with human behavior and associated dynamic activity patterns. Such spaces are visualized as complex adaptive systems, continually engaged in activities of data-exchange resulting in physical and ambient adaptations of their constituting components in response to contextual variations. Equally critical is the underlying interactive process involved in the creation of such dynamic architectural bodies. A collaborative and strategic co-evolution of technical knowledge between the Industry, Praxis, and Academic research gives shape to these interactive constructs, developing an information bridge between three critical knowledge sectors.

Underpinnings

Developing Real-Time Responsive spatial systems is an intricate agenda of Hyperbody's S.M.A.R.T. research agenda led by Dr. Nimish Biloria. S.M.A.R.T. is an acronym for Systems & Materials in Architectural Research and Technology. As a research umbrella, S.M.A.R.T. Environments interrogates the intricate relationship between information systems and associative material formations. This interrogation is deeply rooted in exploring novel interdisciplinary design strategies and nonlinear processes for developing generative meta-design systems. These are used to conceive multi-scalar Performance Driven Architectures and Real-Time Responsive Environments. The resultant spatial outputs are hybrids, which evolve from the creative fusion of Ubiquitous computing, Parametric design and Material computing. Associated experiments spanning from the Micro to the Macro scales, focus on developing context aware spatial eco-systems embedded with sensing, actuation and control protocols enhanced with engineered computing elements and performance driven material aggregations.

The relevance of such real-time responsive spatial systems in the contemporary information rich era and their implications on the shaping of the Architecture Engineering and Construction (AEC) sector is substantial. The rate at which networked data connectivity between objects, machines and humans is omnipresent and is exponentially increasing and has become a key indicator towards exploring such novel spatial paradigms within the AEC sector. This rate of connectivity in the form of the Internet of Things, will fundamentally transform how people will work through new interactions between humans, machines and the spaces which they inhabit. It will combine the global reach of the Internet with a new ability to directly control the physical world, including machines, factories and infrastructure that define the modern landscape. Such data driven synergistic environments bind architectural space and the human counterpart in a behavioral dialogue, promoting real-time interaction. With the advancement in technology, such enhanced spatial environments, are now also increasingly being delegated the task of being more human. This implies acquiring a higher level of intelligence with attributes such as empathy, compassion, pro-activeness etc. becoming intrinsic qualities. It is thus rather crucial to understand how man perceives and experiences his coexistence with advanced machinic intelligence. Besides this, advancements in computational design and analysis tools and techniques have already begun challenging traditional modes of design. An Architectural Engineering flavor, which deals with advanced performance metrics and hyperlinked knowledge banks, is on the rise and is being heavily experimented with by the design fraternity. Performance at the social, structural, environmental and spatial front is thus underpinning contemporary design in praxis as well as academia. Developing fully parametric meta-design systems to enable today's information architect to succeed in this competitive environment is thus gaining paramount importance. The emergence of a new material culture based on novel methodologies in both design thinking and materialization techniques is thus inevitable.

Prototypes

At Hyperbody, we have built a series of prototypes to study the intricacies of research driven design of interactive architectures. The first in the series, called the NSA Muscle, was specifically built for the NSA (Non Standard Architecture) exhibition in Centre Pompidou, Paris, in 2003.

NSA Muscle

The NSA Muscle is a pro-active inflated space, its surface populated with a mesh of 72 pneumatic muscles, which were all addressed individually by means of regulating the amount of air pressure induced within them. The prototype is programmed to respond to human visitors through its sensing, processing and actuating enhancements. To communicate with the observers, the NSA Muscle has to transduce physical quantities into digital signals (sensors) and vice versa (actuators). People connect to the NSA Muscle by 24 sensors attached to reference points on the structure. These input devices convert the behavior of the human players into data that acts as the parameters for changes in the physical shape of the active structure and the ambient soundscape. The input setup comprises eight sensor plates with three sensors each: motion (for sensing the presence of possible players from a distance of 6 meters), proximity (for sensing the distance of the players to the NSA Muscle within a distance of 2 meters) and touch (for sensing the amount of pressure applied upon the surface). The analogue sensor input channels are converted to digital audio signals (MIDI) and transferred to the computer.

The NSA Muscle is programmed to behave within predefined bandwidths of emotional modes and within these modes it is free to act and to develop a personal mood. Emotional modes include jumping (excited), retracting (scared) and shivering (anger) tactile variations attained by volumetric alterations of the external form, by changing the length of the tensile muscles accompanied by the emission of pre-designed sounds of variable pitch. A three-dimensional visualization of the MUSCLE rendered on a flat screen informs the people about the nature of this being. This model is the computational process itself. From this model the state of each muscle is determined. The activity of the muscles is displayed in three colors in the model: red /inflating state, blue /deflating state, and gray /passive state, and in the internally used organizational 72-digit string. Also represented in the model are eight sensor plates changing scale and opacity upon the activity and overall behavioral state of the MUSCLE. They are visualized as a gradually changing color background. Images of architectural applications using muscle technology complement the graphical display. The real-time model is actively viewed from multiple camera positions so as to feel the behavioral patterns at work. Viewed in combination with the physical model the graphical interface contributes to the public's understanding.

Figure 1 The NSA Muscle at the Centre Pompidou, Paris.

Muscle Re-Configured

The Muscle Re-Configured project succeeded the NSA Muscle and focused on materializing a real time, responsive, habitable space, utilizing pneumatic fluidic muscles from Festo. With the objective of experimenting with an interior space, the prototype is conceived as a 3D habitable Strip: a three dimensional section in space, programmed to respond to its occupants through its sensing (proximity and touch sensors), processing (graphical scripting for real-time output) and actuating (fluidic muscles) enhancements. The construct uses a flexible composite panel's (Hylite) property to bend and the fluidic muscle's property of linear compression in interaction with each other, to transform the otherwise hard-edged (visually) spatial strip into soft, luxuriant variations. Each Hylite panel is coupled with two fluidic muscles to form the basic unit of the strip. Panels join together to create a closed 3D loop, in the process creating series of nodes at the panel's junctions. These nodes are linked in space via their actuation members in a highly interdependent manner, constantly exchanging information in terms of air pressure variations, thus behaving as a collective whole to attain varying spatial reconfigurations.

Figure 2 The Muscle Re-Configured being tested for relational curvature variations of all three elements (seating, walls and roof)

This dense network of nodes has two typologies: external and internal. The external (constituting fluidic muscles at the junctions) predominantly deals with sets of sensors and actuators, and the internal (corresponding air valves and their array sequence in the graphical script) deals with computation and data processing elements. A rule-based control algorithm developed in Virtools binds the two node typologies together to produce the desired data exchange and output scenarios (amount of air pressure to be released to the fluidic muscle). The Muscle re-configured project works by means of cumulative coupling of the basic unit mentioned above. This componential interactivity is utilized for developing specific behaviors (in terms of kinetic movements), giving rise to three distinctly behaving elements: responsive floor, ceiling and walls joined together in a closed three-dimensional loop.

These elements are linked in space in a highly interdependent manner, constantly exchanging information (such as occupancy of the seating units, proximity of people, local topology variation of the three elements, etc.). Yet, they behave as a collective whole to attain specific spatial configurations. Seating occupancy triggers a topology modulation in the ceiling and wall units to provide a feeling of being engulfed by the curvature of the ceiling and creates a comfortable viewing angle for projections cast on the wall units.

Emotive Interactive Wall

The Emotive Interactive Wall is composed of 7 separate wall pieces (herein referred to as nodes) that display real time behavior by swinging back and forth, displaying patterns of light on its skin, and projecting localized sound. The primary synchronous behavior of the Interactive Wall is movement. The nodes of the Interactive Wall will bend independently of neighboring nodes in response to the presence of a user. Although responsively independent, each Interactive Wall node synchronizes by constantly readjusting its position in order to align itself with the position of its nearest neighbors.

Augmented modality of the Interactive Wall's behavior is light. The skin of each Interactive- Wall is covered by a unique, irregular distribution of dynamically controlled LEDs that form a highly reactive interface. The LED skins respond directly to user presence by glowing brighter when users are near, and dimmer as they move away. In addition to dimming, the LED skins pulse rapidly and slowly in relation to node position, having a tendency to flash together when the nodes are in sync. The third modality of the Interactive Wall is localized sound. Moments of synchronicity are represented by calmer sounds, while asynchronous behavior results in more intense sound. The propagation of the sound from high to low intensity is varied throughout the Interactive Wall, thus each node is a member of a choir that sings a complex pattern of oscillating chords. Although similar, the physical movements of Interactive Wall, and the light and sound patterns change independently, reacting at varying rates. The synchronous behavior between the Interactive Wall nodes contrasts with the behavior produced by user presence, resulting in a series of complex wave patterns that propagate through the Interactive Wall structure as a whole.

Starting from a clear interactive design concept, we successfully developed a one-to-many interactive system that exhibited emergent behavior and performed like a living system. The result is an independent system built on synchronous behavior that is interrupted by the game-like response of multi-participant interaction. This layered system encourages the intended cycle of observation, exploration, modification, and reciprocal change in the participant, reinforcing believability in the system, and providing a sense of agency to the user.

Figure 3 The Emotive Interactive Wall (commissioned to Hyperbody by Festo).

Ambiguous Topology

Ambiguous topology is an immersive multi-modal installation exploring the tendencies of swarm systems and volumetric projections to generate emergent geometric networks as a response to as well as a trigger for movement of multiple bodies in space and time. The installation operates on the subtle fusion of physical and digital media by means of harvesting and impacting the speed and frequency of movement of the participant's body as a trigger for activating/disturbing a swarm of digital particles in space. The usage of volumetric light projection media (using four HD projectors) in order to visualize this dynamic (simulated) swarm scenario renders abstract three dimensional topological nuances (from projected light) within which the body navigates and experiences new states of ambiguity, dis-alignment and proactive behavior. Technological, human and spatial agency/affordance thus unites into a never-ending looped process of inter-performance through the Ambiguous Topology installation. The installation challenges conventional modes of perceiving space as a dormant object and abolishes the subject-object relationship, which have long been associated with it.

The installation also physiologically and psychologically appeals and instigates our regulated behavioral selves resulting in the generation of novel reactions and interactions. Different geometric instances of the fluid environmental topology are generated via the interplay between the participants and the conceived system, and are materialized via the immersive light projection (volumetric projection) system as a meta-narrative. As a result, an intimate relationship between the overall environment and participants naturally appears during the experiential phase. Meanwhile, an information feedback loop is at play, which binds the physical interactions of the participants, with soft simulation and computation processes to ultimately impact and influence the participants' behavior in real-time. During the interaction process, novel movements, group dynamics and gestural novelty came to the fore.

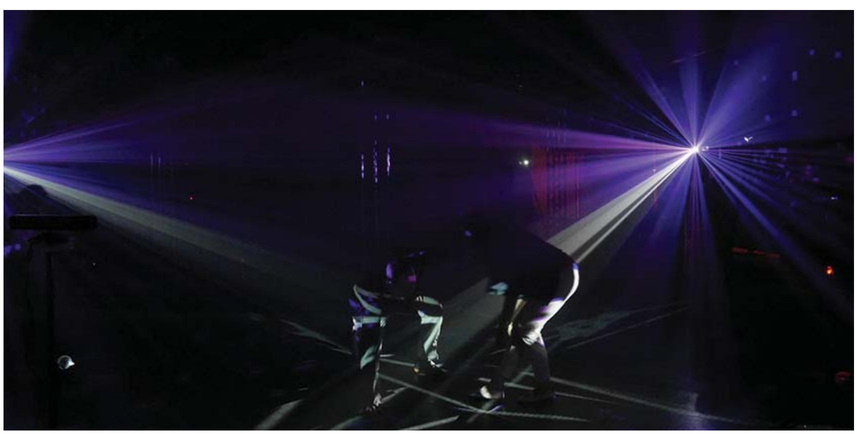

Figure 4 Ambiguous Topology is a Swarm simulation and Volumetric Projection driven fully immersive spatial environment developed at the intersection of art and science
(Video link: https://vimeo.com/105421757)

Reflectego and Robo-Zoo

Reflectego and Robo-Zoo were interactive installations developed under the EU Culture Grant: METABODY. Reflectego is a real-time interactive architectural installation derived from a kaleidoscopic composition of faceted mirrors, aimed specifically at distorting perception. In the project the user literally becomes the physical object inside a kaleidoscope in which he sees his image scattered and recomposed as a result of his movement in space. The structure consists of a suspended faceted mirror-surface with embedded proximity sensors, which hovers and physically changes the inclination and directions of its facets in real-time based on the people it can sense below it. The user is thus visually displaced, since his perceptual affinity of seeing him/herself in a mirrored surface is suddenly challenged.

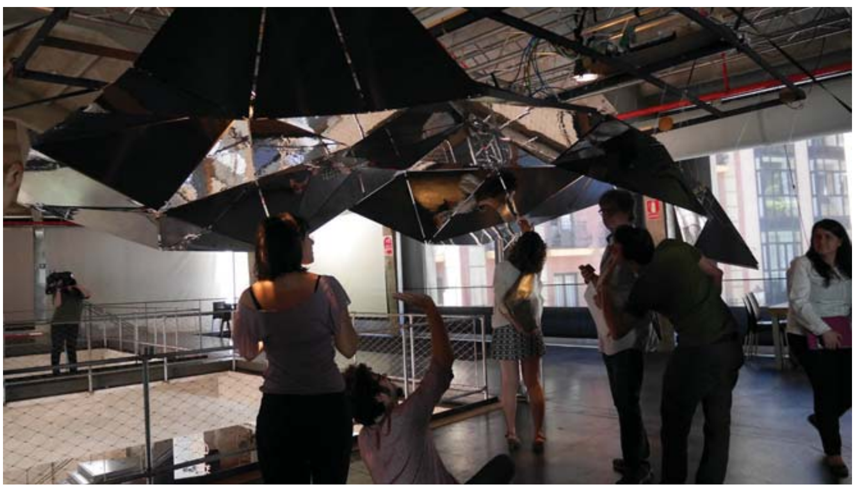

Figure 5 Reflectego interacting with its audience at the Media Lab Prado, Madrid, Spain.

Robo-Zoo creates an artificial eco-system from an interactive swarm of robots. The robots, conceived as small-scale bots operate as individual agents, with embedded proximity sensors and servo motors, powered by a battery pack. Each agent thus has a capacity to sense its context (people and obstacles) and propel it in different directions via servo motors attached to structural wheel spokes. The bots and humans, thus inter-activate each other in order to create novel movement patterns of both and in the process constantly redefine space via establishing unspoken ecological dependencies.

Motion and visual expression of each independent robot evokes instantaneous response in the environment. People perceiving remodeled swarm of artificial creatures are forced to reestablish themselves in the space in real time. Robots and humans thus negotiate interaction boundaries and acceptance levels mutually.

Conclusion

The real-time responsive spatial prototypes mentioned in this article outline the relationship between information flow, material systems and human behavior. Relational data exchange between multiple parameters becomes embedded in the D.N.A of such real-time interactive environments, converting them into metabolic systemic entities. Such spatial constructs will thus eventually acquire the characteristics of living entities, sending and receiving information, processing this information locally, and producing responsive global output. Such design informatics-based hybrid typologies can be seen as complex adaptive systems, which pave the path for performance based responses to contemporary socio-cultural conditions.

Dr. Nimish Biloria is an Assistant Professor at the, Architectural Engineering and Technology Department (Chair: Hyperbody), TU Delft, The Netherlands. He firmly believes in digitally driven bottom-up methodologies for developing performance driven sustainable and energy efficient design solutions at variable scale. His research and education interests in Performative Design and Interactive Architecture are clubbed under the research umbrella 'S.M.A.R.T. Environments' which investigates the intricate relationships between information flow and associative material formations. Investigations under this research umbrella include the following: Interactive Architectural Systems, Interaction Models and Cognitive Systems, Material Systems and Performative Architecture and Smart Cities. He holds a PhD from the Delft University of Technology in Real-time interactive environments and a Masters in Architecture in Emergent Technologies and Design from the Architectural Association, London, UK. He has lectured at several prestigious institutes globally and has also presented and published his research and design deductions via numerous international journals, design conferences, exhibitions, design books and magazines.