ENVISIONING THE RESPONSIVE MILIEU: An investigation into aspects of ambient intelligence, human machine symbiosis and ubiquitous computing for developing a generic real-time interactive spatial prototype

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Abstract. The research paper exemplifies a design-research experiment conducted by the Hyperbody research group (HRG), TU Delft, Faculty of Architecture under the supervision of the Author and Prof. Kas Oosterhuis (director HRG and ONL). The research work, specifically aimed at developing a real-time interactive spatial prototype, fostering multiple usability of space: ‘The Muscle Re-configured’. The ensuing Muscle Re-configured project is essentially an architectural design research undertaking manoeuvring on the precincts of augmented and virtual reality, exemplifying a fusion between the material and the digital counterpart of the architectural domain. This fusion is attained through harnessing a synergistic merger between the fields of ambient intelligence, control systems, ubiquitous computing, architectural design, pneumatic systems and computation (real-time game design techniques). The prototype is visualized as a complex adaptive system, continually engaged in activities of data-exchange and optimal augmentation of its (system’s) components in accordance with contextual variations.

1. Underpinnings

The Hyperbody research group (HRG), TU Delft, functions as a research body driven by contemporary information communication technologies, specifically focusing upon issues of collaborative design in a media (digital and electronic) augmented spatial environment. The notion of visualizing a real-time interactive environment, at the HRG is conceived through building a generic connectivity with virtual prototypes (representative of existent spatial scenarios) articulated with parametric relations and embedded sensing technologies. Such inclinations allows one to simulate emergent spatial behaviours through real time data exchange, connectivity and a networked nature of the architectural grammar constituting corresponding physical prototypes. Simulating real-time scenarios through multi player game designs, re-formulating real life constraints in a structure of logical rule settings and an optimal usage of an elaborate sensor field to develop a complex
adaptive architectural systems underlie the research ideology of the Hyperbody research group.

The HRG, worked consistently with ONL, a multidisciplinary design office (directors: Kas Oosterhuis and Ilona Lénárd), where architects, visual artists, web designers and programmers work together and join forces, practicing the fusion of art, architecture and technique on a digital platform, to develop the spatial prototype: The Muscle reconfigured. The prototype is essentially a re-configured version of an interactive installation: the ‘Muscle’, developed by HRG and ONL for the Non-standard Architecture Exhibition 2004, Centre Pompidou Paris (Figure 1).

3. The Muscle Re-configured

The Muscle Re-configured, prototype is developed as an evolved version of the afore mentioned ‘Muscle’ project, though the core conception, of utilizing Pneumatic actuations as a medium of producing tactile variations persists (utilizing the same set of actuating components: Pneumatic Fluidic Festo muscles). Conversely, instead of the soft volumetric alterations of the external form (as was materialized through the ‘Muscle’ project) this novel prototype embodies an approach emphasizing internal spatial response. The soft inflatable skin of the ‘Muscle’ project, experiences...
a complete reversal of material aesthetic owing to the usage of ‘Hylite’ panels for constructing the prototype’s spatial envelope. The notion of utilizing the shear compression power of the pneumatic muscles, to bend and warp the hard-edged Hylite compositions into soft, luxuriant and meaningful variations is successfully accomplished by the Muscle Re-configured installation.

3.1. MULTI-DISCIPLINARITY

In order for the proposed tactile variations, to attain a meaningful substantiation, materializing an intuitive responsive reaction (the root of the research) towards the occupants of the spatial loop became quintessential. As a result, the multi-disciplinary construct: the prototype, is formulated as a strategic alliance between the fields of ambient intelligence, control systems, ubiquitous computing, architectural design, pneumatic systems and computation (real-time game design techniques) and is highly instrumental in mapping the inherent linkages prevailing between these fields of concentrations. This synergistic approach (Figure 2) towards conceiving the spatial prototype substantiates a generic systems view (open-systems) for conceptualizing architectural space and hence the central issue of fostering multiple usability of space via spatial augmentation attains the dimension of constructing an adaptive system continually engaged in activities of data-exchange and optimal augmentation of its own self.

A systematized exploration into the above mentioned research fields led to the careful extrapolation of specific threads of interest which were instrumental for binding the material and the digital components of the prototype: parametric design—via real time information exchange between software and hardware components, control systems—embedded sensing and actuation technologies, ambient intelligence—focusing upon human-computer symbiosis, pneumatic systems—identifying actuation possibilities, computing—utilizing graphical scripting techniques (Virtools: interactive game design software) and ubiquitous computing—interdependent nodal networks. Such techno-logical inclinations, and a bottom-up systems approach allowed one to simulate emergent spatial behaviours through the resulting real time data exchange between the prototype and its contextual settings.

4. Envisioning the prototype

The prototype is visualized as a three-dimensional section in space, which is cohesively programmed to respond to human occupants through its sensing, processing and actuating enhancements (Figure 3). This three-dimensional strip/loop like conception in space, akin to a genotype, embodying the behavioural logistics of a typological variant, further hint upon the possibilities of developing an ever expanding programmable spatiality by simple means of attaching similar
spatial strips (each delivering specific performance criteria) in succession. The experiment was hence seen as a platform to encourage meaningful spatial mutations, which would result in the production of a networked bio-system of intelligent archetypes. The prototype, as it stands now, is a scenario driven, singular loop developed for testing purposes. The notion of conceiving the whole through successive agglomeration of individual components in a rather systematized manner (by means of developing inherent communicative connectivity), further lead to envisioning the prototype as a collective whole. This conception ensued a strategic extraction of system components to be woven as a singular entity, actively communicating with each other.

4.1. THE BOTTOM-UP APPROACH

An exhaustive methodological dissection, in order to materialize such a complex adaptive system has been charted out, by incorporating a bottom-up design perspective. The entirety of the system is seen as a product of a generic interaction between the soft (virtual/digital) models, representative of constructed scenarios.
and the hard edged world of architectural reality, essentially the hardware/system components constituting the system architecture. A detailed list of the system components, further segregating them in accordance with their generic usage led to the identification of the following typologies:

4.1.1. Pneumatic Entities
Fluidic Muscle Type MAS: A flexible tube with reinforcing fibres in the form of a lattice structure for up to 10x higher initial force compared to a cylinder of identical diameter. The muscles tend to contract 20 per cent of their initial length with the induction of air pressure, hence making it act as an actuating device to alter the node positions of the prototype.

Properties: Diameters 10, 20 and 40 mm, rating length 30 ... 9,000 mm, no stick-slip effect, low weight, hermetically sealed.

Application: Actuating devices connecting the Hylite plates into a singular networked whole.

4.1.2. The Black Box
A hard-edged box housing the switching mechanisms: I/O boards connected to the 72 valves controlling the air pressure lock of the Fluidic muscles. The box has provisions to attach the compressed air intake pipes through distribution channels; houses the CPU and power back-up mechanisms.

Application: Used as a secure container, housing the brain of the installation through which the Fluidic Muscles are instructed to attain the contraction or relaxation modes.
4.1.3. **Flexible Skin**

Hylite panels: Hylite is a sandwich sheet comprising two thin aluminium layers with a plastic core in between. It was developed for car body parts. It integrates high flexural stiffness and extreme lightness, compared to a steel sheet with the same flexural stiffness (0.74 mm) and aluminium (1.0 mm), Hylite is 65% and approximately 30% lighter respectively. These results have been obtained by combining the best properties of aluminium and plastic in a single material. The Hylite panels were specifically selected for the skin of the prototype due to its flexibility criterion and the ease involved in its handling.

Application: Spatial envelope, interactive furniture surface, projection surface

4.1.4. **Control System**

Sensing devices used to enrich the activity recognition criterion of the prototype. The selection of the sensors, involved two basic distinctions in the manner in which we wanted data to be sensed: firstly, the global level—dealing with proximity of users with respect to the prototype and secondly, the local level—dealing with finer adjustments made to the panels by means of individual inputs through touch sensors, hence providing partial control by the user.

Proximity sensors: for sensing the distance of the occupant from the installation (specifically attached to the furniture elements).

Touch sensors: for sensing the amount of pressure exerted upon a surface (specifically attached to the furniture elements: seating surfaces).

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*Figure 6. Spatial envelope.*

*Figure 7. Touch sensors.*
4.1.5. **MIDI and PCI Cards**

*MIDI:* Digital to Analogue and vice versa converters: connecting the sensor input channels and the actuator output channels to and from the CPU. The MIDI was used as a middleware for transferring data sensed through the sensors: both proximity and touch sensors to the processing scripts made in Virtools. These sensor inputs (essentially analogue) are primarily converted into digital format through the MIDI and further update sets of arrays that are envisioned as a dynamic database for the sensors themselves.

Application: Used for sensed data transfer (analogue) to the CPU (digital).

![Figure 8. PCI set up for MIDI.](image)

*PCI Cards:* were specifically used to handle the output processed via the processing scripts. These are termed as ‘Smartlab controllers’ developed at ONL and HRG, and are specifically programmed to receive the output signals (a long numeric string corresponding with the number of fluidic muscles, indicating the status shift of each node: on/off) and communicate them to the In/Out board mentioned earlier (black box), hence controlling the sequential opening and closing of airlock valves.

Application: the PCI cards specifically deal with the output part of the system and help in attaining appropriate spatial variation of the prototype through actuators (fluidic muscles).

4.1.6. **Game-Design Software**

*Software:* Virtools Dev 3.0, software is used for developing an inherent connectivity between the sensed data and the expected behaviour output from the prototype (by means of programming output rules for the system). The software is used as the main computation tool which receives inputs from the MIDI device (sensed data), processes data in accordance with the scripted behaviours programmed into it and sends output digital signals via PCI cards device, which are directly linked with actuating mechanisms.

The graphical scripts are systematically composed to communicate dynamic data, related with proximity of users (through sensors) to a set of arrays built into the software file, which act as the interface between the real and the virtual worlds. These arrays are constantly updated via the ‘sensor reading script’ developed at the HRG, which primarily utilise the MIDI inputs for this purpose. Apart from this script, a parallel operation which concerns the Status of each system unit: 1 Hylite
panel attached with two Pneumatic Muscles, is tracked constantly in real time by means of updating the corresponding valve status linked with the pistons. These two operations formulate the so-called first level operations of the scripts, which are aimed at capturing the context within which the prototype is embedded.

The second level involves the ‘data processing’ script to check in parallel with the previously acquired information: the Status and the sensor reading scripts, hence abstracting the change in context by means of reading the updated array and the current position status of each system unit. This information is gathered by means of compiling it in the form of genotypic numeric strings, which are forwarded to the Smart lab PCI cards.

The PCI cards, as mentioned earlier, further relate these numeric strings in correspondence with airlock valves status and runs re-checks for any updated arrays in parallel to create a phenotype string, which involves a long numeric string equivalent to the number of pneumatic muscles in the prototype and represents the new on, off status commands by means of numeric 1 and 2 codes. This processed data directly communicates with the airlock valves and results in the opening/closing of valves corresponding with the numeric data delivered to the black box, hence actuating specific sets of pneumatic muscles to produce an appropriate system response.

5. **System performance**

The system architecture conceived to bind the above mentioned components successfully transmits contextual data by means of the systems sensing capabilities to the behaviour enriched graphical scripts developed in Virtools, where rule-based computations generate optimal solutions in terms of digital parameters controlling the switching mechanisms of the pneumatic system, directly affecting the compression factor of the actuating elements (the fluidic muscles linked to the Hylite panels), to generate the real-time augmentation. The prototype, at the scale of subsystems is further typified into three units: Relaxing furniture units (relaxation chairs and table), Responsive ceiling units, and Responsive wall units.

5.1. **RELAXING FURNITURE UNITS**

The furniture units are viewed as a hybrid entity, constituting of two sheets of Hylite fixed together (as the seating surface) which are supported underneath by rows of wedge shaped Styrofoam blocks, with two wooden sections on either end of the unit. This hybridization is aimed at increasing the strength of the otherwise fragile Hylite sheets in order to allow people to sit/lie down on the furniture entities. The wedge-shaped blocks, lock together as the surface curves. This variable curvature of the units is a result of the compressive force, which is generated by the fluidic
muscles, fixed at either ends to the wooden sections of the unit. The muscles, in turn are actuated when they receive the appropriate signal from the data processing units (the internal nodes).

This actuation works at two stages by means of two sets of sensing devices: firstly, the data, concerning with the proximity of people near the units is captured by means of proximity sensors, embedded at the facing edges of the furniture units. This sensed data, captured as analogue signals is transmitted through the MIDI interface (where it is converted to digital signals) to the CPU, where the data is processed through Virtools (interaction design software) to return actuation commands which are re-routed through the PCI cards interface and sent back to the Black box to trigger the Muscle contractions. The first stage creates an initial curvature in the furniture surfaces, enough to allow people to sit on it. The second stage involves a much more direct interaction of the people sitting on the furniture surface. The surface has two touch sensors attached to it, which trigger the adjustments in height and curvature of the furniture units (Figure 9).

The data communication, this time, concerning the amount of pressure exerted on the touch sensors, follows the same sequence as mentioned for the first stage and hence materializes in appropriate curvature variations in accordance with the choice of the user. The actuations are not only limited to the furniture units but also extend to the enveloping surfaces: the walls and the ceiling units in immediate vicinity of the seated occupant.

5.2. RESPONSIVE CEILING UNITS

The ceiling is materialized as a network of connected Hylite panels. These panels are placed in position by creating rigid connections between them with the fluidic muscles. The positioning/orientation of the panels is directly related with the manner in which the ceiling units have to operate (Figure 10). The operation involves the creation of projection surfaces, generation of smooth curvilinear soothing forms for relaxation purposes and for materializing openings in ceiling surface for allowing light to venture through. These operations are visualized with one connecting property of the fluidic muscles: the compression forces that it can
generate (which will in turn bend the Hylite panels) and the ease with which they can be linked together to create one long string of compression elements.

![Image](image_url)

*Figure 10. Responsive ceiling units.*

The ceiling units have been programmed to operate in two modes: the local level, and an automated behaviour setting (pre-programmed). The local level, as mentioned earlier, specifically deals with the users input: touch sensor readings obtained from the seating units. The ceiling units directly above the seating units are bound together hence acting in co-ordination with each other. Pressure exerted on the touch sensors, also creates a subsequent change in configuration of the ceiling units, creating a harmonious spatial augmentation. The automated mode is set into action if the prototype doesn’t encounter any activity in its immediate context and hence uses this tactile response as a manner of attracting potential users. This automated performance is pre-programmed in Virtools, and is attained by simply instructing the air lock valves corresponding with the Pneumatic muscles (connected to the ceiling Hylite panels) to induce air pressure if no sensor data is received (which results in null updating of arrays) within a set period of time.

### 5.3. THE RESPONSIVE WALL UNITS

The wall elements constitute the same generic Hylite panels, which are woven together to create a continuous surface with the ceiling elements. The same principle of compression strengths goes into materializing the wall, which, when actuated bends to create projection surfaces and seating surfaces (Figure 11). The actuation of the wall and ceiling elements are also intrinsically linked up with the furniture element actuations, hence weaving the entire construct into a cumulative whole. However, there are also provisions in which, for experimental reasons, one can individually trigger these entities.
6. Conclusion

The installation performs in Real-time, transforming from a hard-edged rectangular sectional strip to a much more softer, humane envelope (Figure 12). This shift from the traditional modes of perceiving space as a closed container object to a more subtle responsive body is intimidating and perplexing at the same time. The Hyperbody research group worked in a rather consistent manner with ONL, over a period of three weeks, to materialize this vision, which has been an exciting experiment in developing spatial alternatives and visualizing a responsive whole. An intuitive interaction, opinionated towards seamless information exchange is initiated through the research experiment, hence transforming everyday utilitarian space into an inter-activating responsive organism. The prototype, convincingly fuels the idea of developing pro-active spaces communicating and reconfiguring in real-time, while being sensitive towards their context. The successful accomplishment of the project is also suggestive of the benefits yielded by a collaborative manner of working with varying fields of expertise and stresses upon further envisioning emotive architectural beings which understand and respond to its occupants.
Acknowledgements

I would like to acknowledge the collective effort of the MSc 3 Hyperbody research group students (Roi Harrari, Jaroslav Hulin, Klaas Jande Koning, Johannes Krohne, Sebastian Lippok, Simsa McNally, Antonio Pisano, Chris Fox), ONL (Kas oosterhuis and Dieter Vandoren), and the HRG student assistants (Chris Kievid, Christian Friedrich, Misja Van Veen and Sven Blokker) for making it possible to materialize the responsive spatial construct.