INTERACTIVE ENVIRONMENTS AN INVESTIGATION INTO REAL-TIME RESPONSIVE SPATIAL SYSTEMS

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ABSTRACT

The design-research work illustrated in this article is centred on the emerging field of Interactive Architecture. The real-time information exchanging spatial outputs showcased in the paper demonstrates a fusion between the human, the material, the electronic and the digital domains. This fusion is explicitly attained through a synergistic merger between the fields of human psychology, embedded sensing and control systems, ubiquitous computing, architectural design, kinetic systems and computation. The resultant interactive projects attain the dimension of 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. Interdependent componential networks, where every constituent component of a spatial prototype becomes a potential information hub by means of its ability to collect, process and communicate contextual data. Apart from this, the components themselves operate, as an actuated detail owing to their ability to kinetically re-position themselves in three-dimensional. A strategy apt for binding physical with the digital and the human counterpart is thus illustrated via selected research and design projects conducted at Hyperbody, TU Delft, The Netherlands.

Key words: Real-time interaction, sensing, actuation and control systems, performance, adaptation, human computer interaction

1. UNDERPINNINGS

The contemporary environment is increasingly being engulfed in a networked digital information exchange based paradigm. The potential of re-envisioning the physical environment itself as an interface to this very digital medium, thus becomes an interesting proposition. It is in this context that the paper explores the importance associated with information regulation and the creation of the much-speculated real-time interactive forms of architecture, which thrive on a purposeful fusion of the

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digital and material domains.

As proposed by Ishii and Ulmer 1997: towards seamless interfaces between people, bits and atoms [1], the paper stresses on the idea of giving physical form to digital information by coupling the dual worlds of bits and atoms. The age old conception of architectural space as a closed system is seen as a complete contrast through this paper to perceive architecture as a subject for real time adaptation.

The systemic prototypes, expanded upon in this paper are conceived via multidisciplinary studies in the field of emergence [2, 3], natural systems and self-organization. The paper exemplifies the dynamism inherent in biotic systems, and applies the study of such complex systems through a synergetic merger of the fields of electronics, material technologies, embedded computation, sensor and actuation systems and swarm behaviour based principles. The products hence are an active contribution to the much-researched field of information driven, real time interactive architecture. The paper exemplifies information exchange by means of tactile augmentation of physical structures and ambient modulations of associated media such as sound, light and colour generated as a response to human, environmental and contextual intervention. Tangible adaptation is manifested via integrating physical materials with digital, electronic and information media. Carefully assigning the generated data into a display that successfully masks the information into new forms and gestures (by means of the nature of information generated, the tectonic variations etc), in the visual, tactile or audio space (multi-modal) is thus speculated through the research investigations.

Besides this, some of the projects illustrated in this article are the resultant of a strategic fusion between Industry, Praxis and Academia sectors. Such collaborations typically involve series of associative brain storming, simulation, prototyping and testing sessions focusing upon the usage of pneumatic and electro pneumatic technologies, interaction design concepts, integrated control systems, structural stability and performance aspects concerning the conceptualized spatial configuration of the system. Experimentations with material systems as regards their flexibility, shape retention and strength ratios coupled with kinetic structural systems formulate a vital part of the collaborative research agenda. Parallel research and development in interaction design, ubiquitous communication, creating computational routines via strategically using a mixture of software as well as developing project specific sensing networks are also carried out under such collaborative design initiatives.

Context, for such interactive bodies, instead of being understood as physical attributes such as fenestration, scale and aesthetics, is understood as a dynamic data set of continually monitored parameters such as density of people, temperature variation, humidity levels, noise levels etc. Understanding context as a dynamic information field of intensive and extensive parameters is thus deemed essential in the development of a meta-system, or in other words creating a 'soft' computationally enriched open systemic frameworks (informational) which, in real-time interface with the 'hard', material component and the users of any interactive architectural body developed by us.

2. ADAPTATION AND INTERACTION

Adaptation, at a physiological, behavioural and structural front is a vital aspect to be considered while developing such Interactive projects. The study of this phenomenon results in discovering inter-disciplinary bridges of knowledge. Adaptation, when looked at from the perspective of Evolutionary Biology, concerns the origin of species from a common descent and the decent of species, as well as their change, multiplication and diversity over time. Adaptation as a process can thus be defined as the change in living organisms that allow them to live successfully in an environment. It enables living organisms to cope with environmental stresses and pressures. According to Julian Huxley [4], adaptations can be categorized as structural, behavioural or physiological:

- Structural adaptations are special body parts of an organism that help it to survive in its natural habitat (e.g., skin colour, shape, body covering).
- Behavioural adaptations are special ways a particular organism behaves to survive in its natural habitat (e.g., phototropism).
- Physiological adaptations are systems present in an organism that allow it to perform certain biochemical reactions (e.g., making venom, secreting slime, and homeostasis).

These three features, namely structural, behavioural and physiological adaptation, in the architectural domain formulate the crux for developing bottom-up interactive spatial systems. A component based approach can thus be embarked upon where akin to cells in natural systems, components can be seen as intelligent building entities endowed with abilities of structural, behavioural and physiological adaptations. In the case of building components, adhering to a performative agenda (per component) the three aspects of adaptation can thus be seen as follows:

- Structural adaptations is seen as a by-product of the inter-dependence between geometry, material and fabrication based affordances in order to produce structurally stable component variations (e.g. Creating morphological variations of the same component in terms of shape, size)
- Behavioural adaptations is closely associated with the domain of responsive interaction which the component should inherit in order to successfully survive and communicate with its context in both active and pro-active ways (e.g. kinetic abilities, information exchange abilities, ambient abilities, sensorial abilities)
- Physiological adaptations in the case of building components is directly linked with the manner in which the component can deal with issues of self sustainment (e.g. energy conservation, retention and dispensation abilities, power generation, distribution and circulation abilities)

Interaction is a terminology used to elaborate the action, which occurs as two or more objects have an effect upon one another. The generation of a two-way effect/dialogue instead of a one-way causal effect/monologue is the basic underlying principle for Interaction. The combinations of many such, simple interactions can lead to surprising emergent phenomena. Interaction has been interpreted in a variety of manners in differing fields of sciences such as medicine, communication, media art, physics, sociology and statistics.

What is of interest however is the manner in which all the above-mentioned fields adhere to the phenomenon of pro-active communication. The area of Physical Interaction where a technologically mediated whole is conceptualised with the central issue of Interaction is of specific importance to such interactive prototypes. The physicality of space itself tends to be perceived as a subject (rather than the modernistic/industrial objective notion), possessing its own behaviour, which is carefully developed with a user oriented (Human computer interaction) perspective. A response (programmed in accordance with event based scenarios), specifically acting upon the interpreted logic from a received message/action (sensed data) formulates the basis for a successful Interaction. Such responsive behaviour is specifically termed as Interactivity. Interactivity is similar to the degree of responsiveness, and is examined as a communication process in which each message is related to the previous messages exchanged, and to the relation of those messages to the messages preceding them – Sheizaf Rafaeli. The understanding of the term is further clarified when taken into consideration the degree of responsiveness substantiated in the interaction process. As Sheizaf states, there are three basic levels of Interactivity: Interactive, Reactive and Non-interactive. These respectively account for the following levels of response:

- Interactive: a state when a message is related to a number of previous messages and the relation between them
- Reactive: a state when a message is related to only one previous message
- Non interactive: when a message is not related to previous messages

What this implies is that in the case of Interactive and Reactive response, the roles of the sender and the receiver are interchangeable with each subsequent message. Thus, a basic condition for interactivity to prevail is a coherent response from each communicant, in the case of this paper, between people, space and the context.

3. DESIGN RESEARCH PROJECTS

The following design research projects are exemplified in this section: The Emotive Interactive Wall, The Muscle Re-configured, The Muscle NSA and Performative Building Skin Systems. The projects are specifically selected in order to showcase multi-scalar implications of fusing the aforementioned discussion on Adaptation and Interaction. Scalar variations ranging from the component scale (building skins), an architectural element scale (wall) as well as an interior scale (interior section of space), are featured in this article. Design driven thinking and the creative, yet, systematic inclusion of computational and technological domains to address the issue of real-time adaptation and interaction of architectural space are thus explained in this paper. Besides the scalar variations, the parameters to which, these experiments respond also vary. Environmental variations (sunlight, wind, sun angle), movement of people, proximity of people, speed of approaching an installation as well as the coordinates of constituting components of architectural space are some of the vital parameters that the experiments selectively address.

3.1. The Emotive InteractiveWall

The Emotive InteractiveWall installation was developed by Hyperbody in 2011 as a multi-modal real-time interactive spatial system composed of 7 separate wall elements that display real time behaviour by swinging their body back and forth, displaying patterns of light on its skin, and emitting localized sound in response to the presence of a visitor. As architecture becomes emotive, responsive, and interactive participants can influence its behaviour and vice versa.

Fig 01. The skin of each InteractiveWall covered by a unique, irregular distribution of dynamically controlled LED's that form a highly reactive interface.

The InteractiveWall's multimodality is made up of three behaviours. The first behaviour concerns the autonomous tactile bending behaviour of the walls. This is triggered per wall based upon their proximity to approaching people as well as the speed and frequency of the person's movement in front of each wall unit. The wall units, in time, also start to become aware of their neighbouring wall unit's movement and slowly start synchronizing their wavy motions with each other. The second behaviour concerns the skin of each InteractiveWall, which, is covered by a unique, irregular distribution of dynamically controlled LED's that form a highly reactive interface. The LED skins respond directly to user presence by glowing brighter when users are near, and glowing 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 multiple behaviour of the InteractiveWall is localized sound, representing only the state of the local sync. Moments of synchronicity are represented by calmer sounds, while asynchronous behaviour results more intense sound. The propagation of the sound from high to low intensity is varied throughout the InteractiveWall wall, thus each node is a member of a choir that sings a complex pattern of oscillating chords. Although similar, the physical movements of InteractiveWall, and the light and sound patterns change independently. The synchronous behaviour between the InteractiveWall units contrasts with the behaviour produced by user presence, resulting in a series of complex wave patterns that propagate through the InteractiveWall structure as a whole (Fig. 01).

Fig. 02. Top: The InteractiveWall at the Hannover Messe 2009 displaying real time behavior by swinging its body back and forth, displaying patterns of light on its skin, and projecting localized sound.

Starting from a clear interactive design concept, Hyperbody developed a one-to-many interactive system that exhibited emergent behaviour and performed liked a living system. The result is an independent system built on synchronous behaviour

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.
Real-time adaptation (Fig. 02), in the case of the InteractiveWall, thus became a complex negotiation between contextual data and the three modalities constituting the wall's make-up. The principles of adaptation and interaction in this case, not only apply to the individual panels, with respect to their movement patterns but also extended to the real-time co-ordination of lights as well as sound based adaptations and their relationships per panel.

3.2. The Muscle Re-Configured

This project focused at materializing a real time responsive habitable space utilizing pneumatic fluidic muscles from Festo. With an objective of experimenting with an interior space, the re-configured 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.

Fig. 02. Top: The InteractiveWall at the Hannover Messe 2009 displaying real time behavior by swinging its body back and forth, displaying patterns of light on its skin, and projecting localized sound.

The construct harnesses a flexible composite panel's (Hylite) property to bend and the fluidic muscle's property of linear compression to interact with each other, in order 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. Subsequent panels are joined together to create a closed 3D loop, in the process creating a series of nodes (junctions where the panels join). These nodes, owing to the possession of actuation members, are linked in space 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 (Fig. 03).

This dense network of nodes has two typologies: external and internal node typologies. The external (constituting fluidic muscles at the junctions) predominantly dealing with sets of sensors and actuators and the internal (corresponding air valves and their array sequence in the graphical script) dealing with computation and data processing elements. A rule based control algorithm developed in Virtools (game design software) binds the two node typologies together to produce the desired data exchange and data output scenarios (amount of air pressure to be released to the fluidic muscle). The Muscle re-configured project, works in a componential manner by means of cumulative coupling of the basic unit mentioned above. This componential interactivity oriented approach is utilized for developing specific behaviours (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.

Fig 04. Top: The Muscle Reconfigured being tested for cumulative curvature variations of all three elements (seating, walls and roof), Bottom: The Muscle Reconfigured inviting users to

interact with it with its pro-active behavior at the TU Delft, The Netherlands

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, behaving as a collective whole to attain specific spatial configurations. The seating occupancy status triggers a topology modulation in the ceiling and the wall units in order to provide an engulfed feeling by the curvature of the ceiling units with a comfortable viewing angle for projections cast on the wall units (Fig. 04).

3.3. The Muscle NSA

The NSA Muscle is a pro-active inflated space, its surface being populated with a mesh of 72 pneumatic muscles, which were all addressed individually. The prototype is programmed to respond to human visitors through its sensing, processing and actuating enhancements. To communicate with the players, the NSA Muscle has to transduce physical quantities into digital signals (sensors) and vice versa (actuators). The public connects to the NSA Muscle by sensors attached to reference points on the structure. These input devices convert the behaviour 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 consists of 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 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 24 sensor impulses, interpreted, processed and weighted by several scripts containing multiple levels of behavioural algorithms, affect the system in a variety of ways.

Depending on the active emotional mode the sensor parameters set the actions of the individual muscles thus determining the volumetric alterations of the external form, by changing the length (varying the pressure pumped into them) of the tensile muscles. A three-dimensional visualization of the MUSCLE rendered on a flat screen informs the public about the nature of this being (Fig. 05). 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 colours in the model: red / inflating state, blue / deflating state, and grey / passive state, and in the internally used organizational 72 digit string.

Also represented in the model are the eight sensor plates changing scale and opacity on activity and the overall behavioural state of the MUSCLE, visualized as a gradual colour changing background. Images of practical architectural applications, using muscle technology, complement the graphical display. The real time model is actively viewed from multiple camera positions as to really feel the behavioural patterns at work. Viewed in combination with the actual physical model this graphical interface contributes to the public's level of understanding. The MUSCLE was exhibited at the Centre Pompidou, Paris in 2003 (Fig.06).

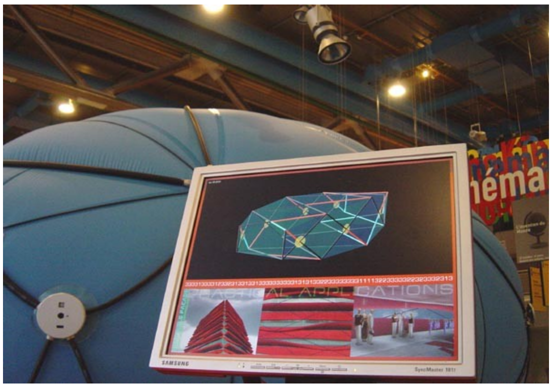

Fig 05. The NSA Muscle’s real-time computational process being shown via a monitor at the NSA exhibition. The activity of the physical muscles is displayed in the digital world in real-time in three colors in the model: red / inflating state, blue / deflating state, and gray / passive state, and in the internally used organizational 72 digit string.

Fig 06. Visitors interacting with the NSA Muscle sensor nodes at the Centre Pompidou, Paris, 2003

3.3. Building Skin Systems

A research experiment conducted at Hyperbody, aimed at developing Performative Building Skin Systems resulted in the production of a skin prototype: The Hyper Human Heart (HHH). The prototype, a real-time light response and climate control based interactive skin system, was developed by means of professional collaboration with an Ethylenetetrafluoroethulene cushion (ETFE) manufacturing company; Buitink, The Netherlands. An ETFE cushion is primarily composed of two thin sheets of a very strong and clear polymer, welded at their perimeters such that the space between the two sheets can be filled with air. The developed component, takes

the form of a flap based shading system made out of PET foil in the form of two triangular movable membranes (the movement of which is controlled by an integrated electro-active actuator connected to a motor) which are fixed internally along the ETFE cushion perimeter (housed within) an ETFE cushion. The movement patterns for the PET flaps were attained via a parametric design based simulation using Generative Components©, in which simulations of the three dimensional model of the flaps responding to the sun position were developed (Figure 7).
The PET flaps are layered with an electro-chromic film, which can change its opacity levels relative to small amounts of electrical current induction. The sandwiched component (Figure 8) also hosts a light sensor (for sensing external light conditions) attached to the external frame and an ultra sonic range sensor (for sensing the proximity of people from the skin) and a touch sensor on the internal surface of the frame.

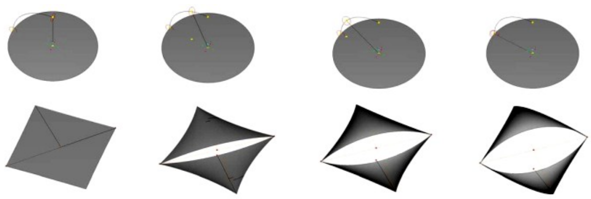

Fig 07. The Generative Components based simulation showing the first row with different sun directions and the second row representing various opening configurations of the PET flaps.

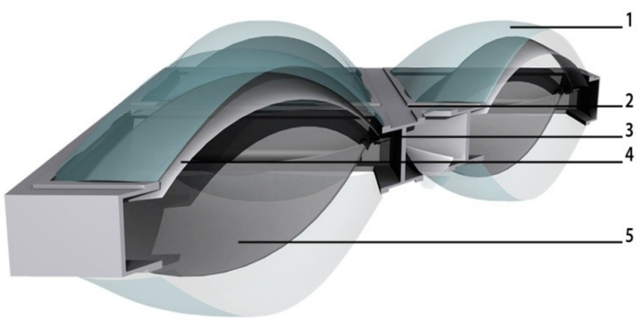

Fig 08. View showing the internal structural make-up of the sandwich component. The ETFE sheets (1) are inflated and connected to the C profiles (2) along their perimeter. The pointer (3) shows the connection point between one of the movable extremities and the small rail in aluminium (that is welded to the C profile). The two movable membranes (4, 5) have a triangular shape and assume two opposite curvatures during their movement.

The readings from the external light sensor and the touch sensors are relayed to a micro-controller embedded inside each component which is scripted using Max MSP & Jitter for activating the embedded motors. The motors are in-turn connected with a kinetic mechanism, which controls the movement of the internal PET foil membranes as a direct response to external light conditions as well as user touch. The actuations of the two motors per component are carefully regulated such that the internal flaps are completely open when the sun angle is horizontal and is closed when the sun angle is perpendicular (in order to allow diffused lighting instead of harsh sunlight).

During the day, the opening system changes proportionally in accordance with the solar inclination by a scripted routine, which will measure the angle between the sun direction on the x and y plane and the perpendicular vector on the skin's surface. This parametric skin therefore remains closed (saving energy) during the night because the sun angle is more than 90 degree.

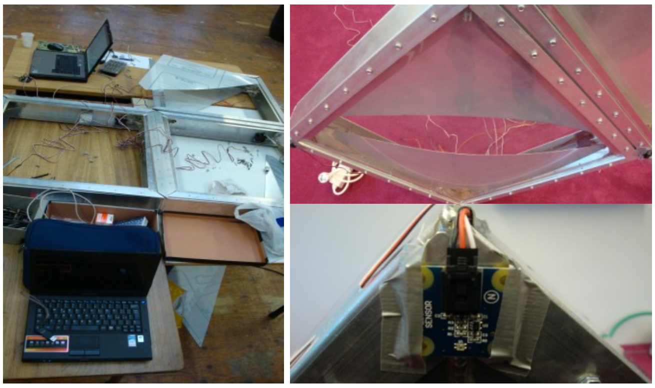

Fig 09. View showing the assembly details of the actuators and motors on the internal frame of the prototype and the mounting of touch sensors on the external frame of the prototype.

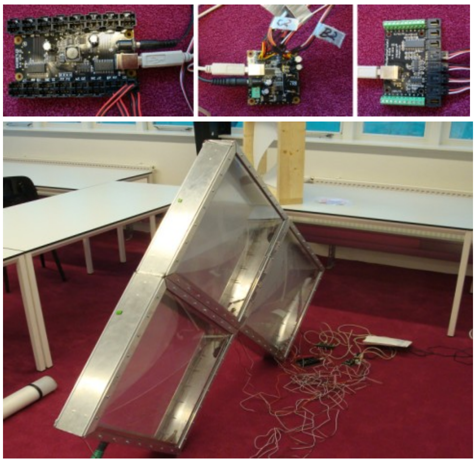

Fig 10. The finished skin as an assembly of three interactive components with built-in micro-controllers and sensing (proximity, touch and light- above) and actuation systems per component.

Users from the inside of the building, on the other hand activate the ultrasonic range sensor and the touch sensor. The ultrasonic range sensor can sense the movement of people in close proximity of the skin. This sensed data after being processed by embedded micro-controllers per component triggers corresponding components to open their internal PET flaps as an immediate response thus providing playful ever-changing skin patterns.

All component on being touched, register this touch via the embedded touch sensor. This reading overrides the aforementioned external light response based actuation and instead via the embedded micro-controller sends a direct response for the motors to open the PET foil membrane to its maximal extent as well as induce a light electric charge for changing the opacity level of the electro chromic film from opaque to transparent. The skin can thus become fully transparent or become a mirrored glass (with a transparency of 30%). The touch sensor operates on a time frame basis: the duration of time for which the touch sensor is pressed the more or less transparent the electro-chromic film becomes. The system also has an inbuilt clock (scripted using MAX/MSP/JITTER), which it uses to reset itself in the default configuration (depending on the light sensor) after being out of use for an hour.

In this way, a direct relation between users and the external skin is created at any point in time thus resulting in emergent opening patterns of the entire skin. The HHH group worked consistently at the Buitink manufacturing plant, where engineers from Buitink helped mount the internal PET system with embedded actuators and sensors to be encased within a pressure pump inflated ETFE cushion thus creating one skin component.

The component thus developed (Figure 9) is an excellent example displaying how fundamental research and praxis can collaboratively develop a meaningful environment based on the idea of performance.

The Hyper Human Heart Project, after developing a physical real-time interactive prototype (Figure 10) undertook a rigorous analysis session conducted by one of the research members, Valentina Sumini [5]. Computer-based analysis using Ecotect© and Radiance© [6], of daylight performance and Day light factors using climatic data for simulating sky conditions for the months of June and December were conducted (Figure 11). The component was populated (southward facing) over the entire façade of a room with the simulation developed by placing the work plane at a desk plane level (0.8 m) the grid values are thus located at this height.
It was found that the illuminance distribution in the two simulations results for the month of June and December is very different. In June the solar altitude is higher than in December and this fact results in a lower value of the external illuminance on the south façade as compared to the results in June where the highest value of external illuminance is on the roof of the room and not in the south façade. The internal illuminance distribution due to the sun position shows that in June, since the sun is much higher, the solar penetration is lower and is thus concentrated in the first part of the room (close to the façade) than in December.
The analysis eventually concluded that this smart component can be considered as successfully serving its performative cause only if its user based interactive aspects are considered as an integrated feature of the entire system. This innovative façade element could also be simplified possibly in the façade's highest areas, which people cannot access. A possible simplification could consist of inserting just one instead of two movable PET membranes with an electrochromatic film overlay (this could also be in the form of a non-movable membrane with an electrochromic glass). This electrochromatic membrane could change transparency according to the external illuminance values and with some iteration in the software system could also develop interaction abilities similar to the current prototype.

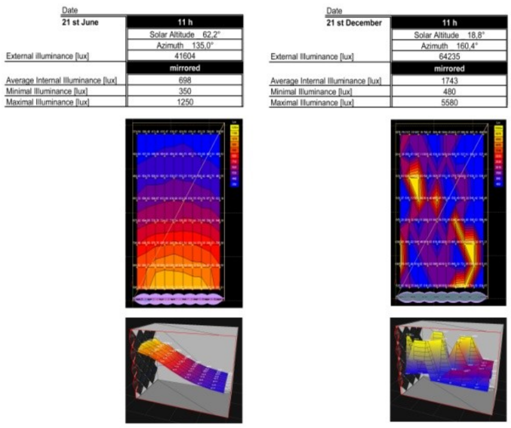

Fig 11. An example image of the extensive analysis showing the results of the daylight analysis on the 21st June and 21st December at 11 a.m.

4. CONCLUSION

The paper exemplifies a paradigm shift in the architectural context by embracing inter-disciplinary approaches towards architectural space making. Conceptualizing and appropriating architecture as an open systemic network provides the designer with opportunities to explore creative methods pertaining to dynamic data flows as well as real-time information processing in order to achieve an intelligent response from the designed entities. The future of architectural space is thus visualized as a transient, real time behavioral body, by means of the illustrated projects.
Information flow becomes a continual process in such real-time interactive spaces, hence converting them into executable processing and reacting systemic entities. Such architectural constructs eventually acquire the characteristics of living entities, sending and receiving information, processing this information locally and producing optimal interactive output. The intrinsic design decision of enriching the nature of architectural detailing and acquiring an inter-disciplinary work process thus has significant impact on the nature of architectural space and its structuring principles.
An intuitive interaction, opinionated towards seamless information exchange is thus initiated through these research experiments, hence transforming everyday utilitarian space into an inter-activating network of spatial correlations. What is also evident throughout the projects is the degree of responsiveness and interactivity, which, via the medium of design driven technological thinking results in multi-modal real-time spatial response. The central idea of developing Interactive morphologies, which inverse the subject-object discourse in architecture is thus successfully experimented with via these selected experiments.

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