Architecture and HCI: a review of trends towards an integrative approach to designing responsive space

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ABSTRACT | Recently, trends in integrating dynamism and response in Computer Aided Architectural Design have been in vogue. Attempts to attach dynamic forces to vector objects and thereby breeding amorphous elements and responsive environments are demonstrated through numerous design proposals in recent times, where design concepts are represented as active systems of forces affecting CAD objects; turning them into responsive amorphous organisms. This intention is compromised once such active forms are translated into built objects from the simulations, which largely remain inert. On the other hand, recent concepts in Human Computer Interaction (HCI) and pervasive computing, have demonstrated relevance in physical objects and spaces; turning them into elements of physical interface to mediate particular human actions, aspects of communication, entertainment and aesthetic expression. While responsiveness grows as a concern amongst architects, allowing HCI features and computational schemes to become integral processes and parameters within architectural design may provide design processes with new approaches to architectural production. This may, in turn, alter the resultant architectural schemes and their behaviour. This paper reviews relevant developments that contribute to such potential to inform physically responsive environments and scopes their integration in heterogeneous architectural design processes.

1 Introduction

With advancing information revolution, architectural space that had earlier been conceptualized, represented and structured to contain localized human events was suddenly faced with new perplexities questioning the relevance of static physical envelopes. This dynamism of information resulted in a notion of space that rather than being understood as a passive container of objects and bodies, was suddenly charged with all the dimensions of a relative, moving, dynamic entity (Vidler 2000). The human event was no more limited to the space provided for it but it rather began expanding into the space of electronic information. A new search to align architectural space to fluidity of information had thus begun. Deleuze's (2001) *'The Fold'* had seemingly been appropriated by a number of designers for the affiliation of smooth and striated space - folding and transforming. Incorporation of terms such as temporality, uncertainty, continual transformation and fluidity that Deleuze developed to describe Baroque thought, into architectural practice has led to significant changes in how buildings are thought of and built. On the other hand, 3D modelling tools, integrated structural analysis software, NURBS modelling, and inverse kinematics have not only

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made conception, design and modelling of previously unimaginable geometries possible but also made it possible to animate these forms. This gave birth to processes that allowed the objects to be linked to dynamic information flows, and be altered; or in other words, it allowed them to respond to dynamic forces that the designer wanted them to respond to through undergoing structural alterations in shape, texture, volume or other physical characteristics. However, such responsiveness and fluidity remains limited to the design stages where one can program the NURB (Non Uniform Rational B-Splines) objects to be stretched, pulled and twisted in response to constantly changing environment staged around them by the designer. Although such methods signal a new departure in architecture where space would no longer be a static container, but a dynamic entity that could morph and adapt to changing situations, what is built, still remains pretty much inert and static.

This paper first investigates processes developed by contemporary designers that favour such organic free form and the animated geometric forms. In the later sections, the compromise between the initial design intensions to include responsiveness in forms, and the inert built outcomes is discussed. Trends in physical computing and HCI (Human-computer Interaction) are examined to identify opportunities for interfacing computational processes and physical objects that may hold possible solutions for architectural design. This review brings forth new conditions for an approach to design, which allows integration of the notions of fluidity, responsiveness and dynamism through the stages of design conception to production of amorphous objects.

2 Some design based attempts to devise dynamic building forms

Despite serious criticism surrounding the literal interpretation of Deleuzean theory in architectural discourse (Vidler 2000)[1], numerous techniques readily attempt to embody these notions in design and production of contemporary space to align it to speed, mobility, and dynamism of information, and thereby sinuous multi-functionality and variation. Growing trends in architectural design tend to weave together active forces with NURB objects (Zellner 1999). Parametric design and computational techniques involving amorphous CAD objects constructed as composite assemblages of parametric descriptions with forces activated from within or applied from outside, as fields or regions of influence, have become predominant practices to breed dynamic spatial designs. *Long Island house* in New York by Greg Lynn is an example resulting from a force twisting the NURB object bound to a skeletal structure. In his proposal for the *Port-Authority Bus Terminal*, (Rahim 2000) pedestrian and vehicular movements from the project site are represented through active particle system dynamically affecting the form. Dynamism is obtained either by attaching active fields of influence over geometry, geometric interrelationships or by mediated algorithmic manipulation of their internal parametric structures and interdependencies.

Animation techniques such as key-frame, key-shape or path-animation[2] often denote multiple methods of interpolating the object, motion and force at the moment of formal conception. In the *WetGRID* installation (Leach 2002) at Musee des Beaux Arts Nantes, NOX applied four rotating forces (vortexes), conceptually

1 "..as designers and theorists have tended to see the Deleuzean model as an invitation for a rather literal folding of the envelope, a complex curving of the skin, that tend to ignore rather than privilege the interior. According to Leibniz, a fold could in no way be replicated simply by the curved surface of a tent-like or blob-like structure, and not only because of its external qualities. The Leibnizian fold is in continuous movement, enveloping former folds and creating new ones on the surface of the diaphragm..and..as an interior mechanism which at once reflects the outside and represents the forces of the inside, is more of a mediating device, a spatial instrument than an object acted on from one side or another"

2 Key-frame and key-shape animations largely form the basis of such techniques where in the former, changes in the geometry are defined as keyframes (keyshapes) along a timeline and the in-between states are computed by the software, where as the repertoire of the latter uses techniques such as the forward and inverse kinematics, dynamics (force fields) and particle emission that structure the forces to exert from outside.

Figure 1: Marcos Novak's algorithmic world, where genetic algorithm applied directly to the parametric description of CAD objects result into dynamic transformation of forms beyond the designers' active control (Leach, 2002)

connected to four types of vertigo and hallucination, on a linear structure of 8 double lines derived from the existing building grid, which represents general orientation within the museum. Changes in the state of the influencing force over time, in turn, induce structural changes in the object. The resultant system hence formed complex nodes and splits within these dynamic rubbery lines under the vortice's influence. A selected moment from this dynamic system was later transformed into a paper model, and eventually translated into a physical installation. In this example, an abstract design concept (i.e. the vertigo metaphor) is represented as a system of dynamic forces (i.e. vortexes) acting upon other representations (i.e. a system of 8 lines depicting general orientation within the building) to produce dynamic systems representing the design solution.

Virtual forces, forces of gravity, wind, or vortex, particle systems, and hydrodynamic formulas are often used to represent subjective design metaphors influencing the resultant spatial scenario. Parametric design often also entails a procedural, algorithmic description of geometry. Using additional software such as *Mathematica*, (Cocke 2000), architects have worked with mathematical models using generative procedures constrained by numerous variables initially unrelated to any pragmatic concerns. Marcos Novak's use of genetic algorithms (Fig.1) to directly alter parametric interdependencies and thereby altering the resultant form is one such example where intellectual concepts represented as mathematical models are applied to inform design solutions. (Leach 2002) Such evolutionary processes apply the rules of reproduction, gene crossover and mutation to breed numerous prototypical forms in small incremental changes over several generations to come to the fittest design solution; selected either computationally or, in most cases, through manual judgment.

2.1 Models applied to generate responsive dynamic forms

Such interplay of forces and forms entails a variety of transformations including changes in object's characteristics, attributes, or interrelationship networks between objects and across their collective character. These include transformations in singular or collective volumes, surface topologies, shape, porosity, transparency, and other attributes, which in turn, induces transformations in various architectural aspects in terms of altered programmatic organisation, spatial character, interrelationships, visual connections, morphology, etc. Within such deliberation, the following procedural models are frequently applied on specific aspects of a digital construct (Fig.2).

- Perceptual forces represented as kinematic systems to affect vector objects (i.e. designer-dependent subjective decisions);
- Intellectual concepts symbolised as digital objects embodying spatial requirements of a given architectural function (i.e. four strings represented

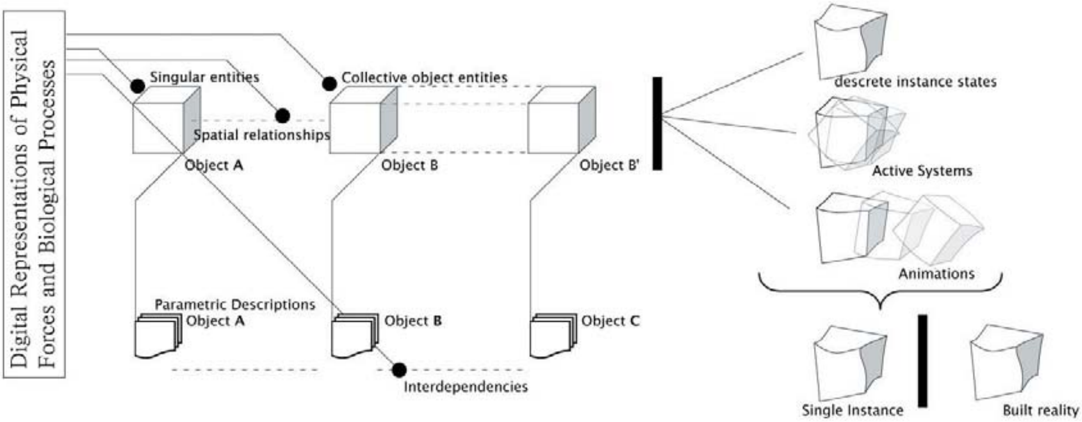

Figure 2: Diagram pointing at the areas within a digital construct where the form manipulation processes are usually applied to obtain animated or responsive entities.

as four types of vertigos in WetGRID installation);

- Digital state of a system (often dynamic) depicted as that of a physical system (i.e. Simulation of traffic patterns affecting the building form in Port Authority Bus Terminal project where a subjective simulation unrelated to real traffic flows affected the eventual built object);
- Associative metaphors containing objects/attributes/actions projected on form/function/program; and
- Design metaphors shaped as particular dynamic systems.

2.2 Conflict between dynamic forms and physically built entity

However, this study shows that the obtained dynamism and responsiveness is eventually isolated from the system towards the end of the design process where a select moment is chosen from the active system (or the animation) to be developed into a built entity. The *Salt Water Pavilion* by Kas Oosterhuis (2002) is one of the few contemporary projects that takes the notion of responsiveness right through the built product where forces from the physical environment affect the state of the built object. Built in 1997 near *neeltje jans zeeland* in Netherlands, this project demonstrates integrated real-time sensing and imaging technologies to alter experiential aspects of space. Additional to two user driven interfaces within the building skin that enable interaction with space, the design also integrates larger programmatic contexts, such as the weather information data stipulating pulse frequency of the colour environment, or information of the changing water levels in adjacent sea affecting other environmental parameters within the pavilion (fig. 3).

Klein-Dytham's (2002) *Bloomberg* renovation and *Water Worlds* by Lars Spuybroek (Oosterhuis

Figure 3: Interior views of Salt Water Pavilion

2002) have demonstrated similar approaches to responsiveness and spatial dynamism through audio-visual media in architectural environment. Although a significant component of such exercises remains debatable from a viewpoint of their relevance to realistic human functions, as such interventions largely operate only within the realms of symbolism and aesthetic expression. Also, this example does not provide much insight into physical augmentation of form. However, what may be inferred is how such design approaches could affect the resultant built-product and expand its performance when design conception occurs keeping embedded computing and interaction in mind, where real world activities, both human and climatic, begin to affect architectural form and its performance.

2.3 Two observations on current trends in architectural design

Considering the contemporary design trends in the light of the above, the following two conflicting observations are evident:

1. The exclusion of conceived dynamism while isolating a select instance from the sentient systems for its translation into built entity;
   and
2. Proliferation of a common desire to developing active spatial schemes, and to formulate and interweave dynamic factors that the schemes may be expected to respond to.

One may justify such proliferation of a desire for such dynamic designs as "new" processes or as procedural methods to obtain nothing but non-standard forms, (leaving aside both, the perplexities surrounding literal interpretation of theories (Vidler 2000), and the questions of logical relevance of such methodologies in spatial design). What is clear is a possibility to investigate methods allowing design processes to incorporate dynamic factors that a designer may want to attach to architectural features, and to undertake an investigation into how such collaboration may inform performative agendas of space. A new genre of animated architectural elements could therefore evolve.

Although most built products resulting from such processes remain passive (or static) at the moment, recent trends in computing demonstrate realistic possibilities to weave together objects, spaces and digital information. Mark (1999) anticipated similar departures through pervasive computing, where most human-computer interaction would become implicit and take account of physical space, as computational devices become part of furniture, walls, and clothing, potentially turning physical space into a necessary consideration in computational design. Developments in ubiquitous and other physical computing concepts demonstrate a growing opportunity for architectural design to seek collaborations and obtain techniques to accommodate desired responsiveness, dynamism and interactivity in built objects.

3 A review of some trends in HCI relevant to design of dynamic, interactive built entities

Recent trends in computing demonstrate a growing desire to interweave computational intelligence and HCI concepts into physical spaces, objects and surfaces turning them into elements of distributed ambient interface (Pentland 2000). The "SmartRooms" of Sandy Pentland and colleagues (1996) demonstrated such departures that make use of human spatial reasoning capabilities. SmartRooms, and Pentland and Liu's "Smart Car"(1999), also concentrate on inferring human intentions through their actions in order to provide enhanced interaction techniques in physical environments. The "Tangible Bits" approach (Ishi Ullmer 1997) grows alongside on the boundaries of human-computer interaction, following the ubiquitous computing paradigm into physical and ambient interfaces tying up objects to information manipulation and computational control, where specific stimuli from the object's surroundings determine it's behavior.

3.1 Tangible paradigms

Concepts for the sophisticated integration of physical objects, human action and information are described by Ishi and Ullmer (2000) in an alternative interaction model to the prevalent MVC archetype *(Model View Control)* for physical computing which primarily include physical representations being coupled with the underlying digital information and the physical representation of digital state of a system. Unlike MVC, which highlighted the separation of the GUI (Graphical User Interface) between the visual representation and the control mediated by the mouse; the later proposal for MCRpd archetype *(Model Control Representation – physical/digital)* by Tangible Media Group at the MIT, describes a new interface model what they call TUI *(Tangible User Interface)*. TUIes developed by the group demonstrate potential for coupling actively mediated digital representations to physical objects where digital information is manipulated/controlled via sensing mechanisms embedded within physical entities, or information represented through changing physical state of embedded actuation media within objects. *Media Blocks*[3] and *Information Windmills*[4] respectively form examples of physical objects being information representation and manipulation media. Physical representations thus embody mechanisms for computational control.

Developments in object-oriented computational concepts suggest applications within the architectural spectrum that may not only provide a wider perspective on design but also numerous possibilities for augmenting various aspects associated with spatial elements.

3.2 Surface based sensing and response

The notion of surface or skin receives an inevitable attention while predominant form acquisition processes increasingly rely on sculpting NURB surfaces. A profound change has been apparent in design, structure and production of built entities (Charles 2000) and objects that grow along what Lindsey (2001) calls a ‘Skin-in’ approach. The importance of the surface is further supported by studies in visual culture (Jencks 1997) that provide cues to recent human obsession for surfaces for their kinship to information and vision. However, the significance of surface in contemporary spatial production points to vital collaboration opportunities for integrating information intake, response and interaction techniques.

3.2.1 Large Sensate Surfaces

Surface based interaction largely involves discussion of embedded sensor systems. Existing methods rely on a variety of systems based on Infrared, LASER, photo, and electromagnetic, ultrasonic or acoustic means for sensing location, pressure, proximity etc. Additional parameters and more sophisticated perceptions are enabled by application of algorithms, interpolation techniques, and computational processes on obtained raw information. Certain smart room approaches describe activity sensing (Lynn 1989) to affect dynamic media. Although much development in sensing techniques over large surfaces either relies on a particular surface plane, or creating a virtual surface against an existing plane; in turn, this limits their applicability to flat surfaces (Paradiso 2000). *Laser Range Finder* (Paradiso 2000) demonstrates one such example where separate control and response planes calibrate with each other forming a large sensate wall in which position sensing is enabled by a reflected LASER beam forming a virtual plane against the physical surface. Other examples in electric field sensing use force sensitive resistors for generating the primary electric impulse. For example, *Magic Carpet* (Paradiso 2000) deploys a grid of piezo-electric wires woven into a textile surface. Being flexible it remains open for applications onto a variety of surface topologies and shapes. Also, pressure sensitive resistors provide

3 See http://www.media.mit.edu
4 ibid

the system with a handle to measure varying pressure values additional to the position coordinates. Use of acoustic sensing over large surfaces has also been described (Ishi 1997) where a tap (or contact) position is measured through differential time of arrival of acoustic signal at four different corners of the surface. For architecture attempting to incorporate forces, actions and activities to enhance spatial experience and augment spatial performance, it is clear that such processes may only be initiated with knowledge and techniques borrowed from the branches of HCI that prove a vital link between the physical and the digital. New heterogeneous approaches to architectural surfaces may also be informed through such collaboration.

3.2.2 Kinematic and Kinetic Surfaces

From the response end, it is important to separately understand the simulated action (Kinematic) and the physical movement (Kinetic) as they form the two basic themes of respectively visual and tactile response. Kinematics pertains to motions unattached to real objects and is therefore only considers ideal situations (mathematical/computer simulated motion graphics). According to this definition, video-works combining moving images with dimensional elements are kinematic and not kinetic. Kinetics, on the other hand, is concerned with motion resulting from forces directly connected with physical systems. Kinetics is therefore inherently associated with physical assemblies. Robotic motion, being mechanical, comes under kinetic media where changes in the state of a physical assembly denote response.

3.2.3 Kinematic Surface-Response

Notions of response in systems based on CAVE[5], VR(Virtual Reality), interactive cinema etc work with manipulating spatiality using surface bound visual means (Penz 1997). Scopes of such response also include simulated motion, attribution transformations such as shape, scale, colour and other optical aspects, additional to video and other dynamic media. *Yellow-wallpaper* (Panayiotis 2001), for example, explores a notion of movement integrated into mediated space. This system enables the viewer to explore story environments from different camera angles as well as from different subjective points of view facilitated by juxtaposing prerecorded video material shot on a blue screen with multiple camera angles, over a dynamic 3D Model of the environment. *Cinemat,* (Panayiotis 2001) grows on similar lines but here user movement is attached to mediated space using an active feet tracking system to allow manipulation of video environments in real-time. The user is allowed in this scenario to explore or change a particular spatial scheme through the location and weight of each step (Paradiso 2000). These examples work with human cognition in two very different ways to demonstrate the idea of motion, physical space and perception. One attaches physical movement to virtually navigate through a representation of physical space (video) and the other enables virtual movement within a representation of physical space. *TelePresence Lounge* (Anshuman 2001) provides another interesting example where sensing and image are integral features woven into responsive surface of a chair that emits dynamic representation of movement enabling abstract communication between two networked users. The physical movement of each user is cross-linked to enable perception of bodily aspects through representative motion.

3.2.4 Kinetic Typologies

Inducing kinetic response in architectural surfaces may include transformations in surface shape, topology, position and other physical properties. Fox[6] (2001) describes kinetic typologies in architecture as *embedded, deployable* and *dynamic* systems based on complexity of control and kinetic properties. 160ft long *Kinetic wall* is a New York based architectural installation[7], a *dynamic* system responding to pedestrian

5 see for more info. http://www.evl.uic.edu/pape/CAVE/
6 see for more info. http://kdg.mit.edu
7 ibid

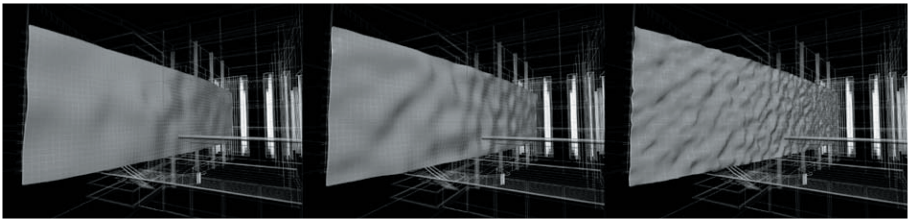

Figure 4: Hyposurface

activity on the street where surface mounted whiskers like motor driven bars rhythmatically point towards mobile targets creating ripple effects through the field. *Hyposurface*[8] (Fig.4) developed by dECOi, on the other hand, proves to be much more complex in how it negotiates with the digital information for its eventual translation into physical animate-skin. Capable of inducing endless topological variations driven by over 8000 pneumatic pistons, the *Hyposurface* forms a milestone in computer driven physical responsive surfaces. A general breakdown of the levels of machines by their ability to adapt to differing needs have been defined by Zuk (1970) where various mechanisms transform kinetic energy by a variety of control apparatus through linear, rotary or composite multi-directional action.

Response typologies in robotics describe a hierarchical framework based on competence of intelligence driving motor activity. Within Deliberative and Behavioural modes of response it organises robotic systems in *Reflexive, Reactive* and *Adaptive* or *Evolutionary* systems (Ronald 1998). All the above examples are reactive or reflexive in how their control-architectures negotiate with supplied stimuli in a constant looping action triggering rather pre-programmed changes in the physical state of the system.

4 Integrated design approach to develop physically responsive spaces

Based on the aforementioned developments, contemporary directions in design clearly suggest a rapidly evolving requirement to link the architectural objects to various larger programmatic conditions and dynamic contexts. Concepts in HCI, on the other hand, have gradually turned to deploy computational control in objects and spaces in physical environment to augment specific performative scenarios from discrete computational perspectives. From an architectural standpoint, these developments demonstrate emergent contexts for new departures in design and spatial production. Incorporating computational techniques and assemblies through the initial stages of design may, in turn, affect the resultant design object in significant ways in terms of its form and performance. For this, kinetic design, embedded computation and HCI models need to be looked at as integral components of a design system. Necessary to this is the use of advanced computational design tools, developments in materials and embedded computation to enable design processes to take advantage of responsiveness using computational techniques. According to Fox[9], “the motivation lies in creating spaces and objects that can physically re-configure themselves to meet changing needs. Such systems may arise from the isomorphic convergence of three key elements; structural engineering, embedded computation and adaptable architecture, with adaptable architecture providing the necessary contextual framework for development”(Fox 2001).

8 http://www.hyposurface.net
9 http://kdg.mit.edu

A design model that may facilitate such an approach to developing objects and elements for spatial applications is currently under development (Anshuman and Kumar 2003). Such approach engenders obvious requirements to develop new design tools to enable such integration and to expand knowledge expertise within design teams. Advantages of such models were clear within the *Hyposurface* team that included C programmers, mathematicians, artists, architects and material scientists (Decoi 2000). Techniques of diagramming, mapping and simulating such heterogeneous systems for architectural production may mean developing an interdisciplinary platform with support from the hardware and software design, mechanical and material knowledge, and expertise in electronics and embedding techniques. This aims to eventually propose such heterogeneous support environment to enable the designer to conceptualise a specific product from a cumulative vision from several technical perspectives. Details of this model are currently under development and hence beyond the scope of this paper.

4.1 Application contexts

Application contexts for such systems demonstrate possibilities for how the built environment could function as an evolving organism that learns and adapts to its user and environment in a symbiotic co-existence. Manipulation of static media (vector or raster information), dynamic media (video streams, sounds or dynamic graphics), digital attributes (colour, size, position and other material properties), computational operations (applications and agents), remote people places objects or devices, simple data structures (data bases), and dynamic data structures (integrated databases, dynamic data, operations and attributes) may result in a variety of scenarios additional to just volumetric and spatial transformations for dynamic spatial requirements. Such contexts may include;

- Information visualisation;
- Gestural / Emotive response;
- Event assistance;
- Environmental performance;
- Entertainment; and
- Aesthetic expression.

5 Conclusions

This paper has reviewed recent developments in two separate disciplines which show a common concern; that is how to integrate the physical systems with often-intangible dynamic activity patterns (i.e. climatic changes, networked data flows, intangible usage patterns emerging from human activities and urban environments etc.). If it is true that all design objects (not only buildings) are developed on some kind of design-contexts considered by the designer, it is also clear that these contexts, until now, depended on static entities or on an arrived optimal static depiction of an otherwise dynamic situation. For example, a conference room designed for 20 users does not always house 20 users. The design context however is an optimal static depiction of an otherwise dynamic context (i.e. *largely* the conference room will be used by 15 to 25 users). However, now with advancing technology, being able to tap into these physical flows is emerging as a real possibility. It is this condition that seems to have engendered a general tendency among designers to somehow devise systems that adapt dynamically to its changing contexts.

In other words, there is also a general interest in using dynamic contexts to inform design objects, to extend design objects' functional apparatus and have the object display information, express its state or interact with its user. While architecture as a design profession does not readily posses technical expertise required for such synthesis, it is apparent in current state of the proposals that architects are interested in experimenting with processes that may allow such synthesis. HCI on the other hand, shows similar concern while context aware systems are now envisioned as the third major wave in computer science. However, HCI's take on the subject comes from the discipline's scientific background. Allowing HCI features and computational schemes to become integral processes and parameters within architectural design may provide design processes with new approaches to architectural production. This may, in turn, alter resultant architectural schemes and their performative apparatus.

Although it is beyond the scope of a review paper to suggest concrete solutions to enable such synthesis, it can be said at least, that cues to enable such heterogeneous design and production processes are rooted in developing a multi-disciplinary design model. Attempts to align architectural space to dynamism and fluidity of information can seek methods and realistic mechanisms to influence space by incorporating human actions, environmental activity and communication patterns. This may be achieved by embedding multimodal I/O devices and adaptive knowledge processing techniques that could enable systems with emotions, reflex, affect and an ability to perform extended tasks through a collective activity of sensing, processing and response media woven into space.

A complex series of coordinated responses may be enabled in reaction to the stimulus supplied through system's physical environment and networked information influx. Adapting such technologies to architectural production could enable built environments that function as responsive organisms assisting the human function by dynamic alignment to a variety of parameters. Such endeavours possess potential for developing objects and environments of a new type that move between the categories of digital and physical.

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