

SCALELESSSEAMLESS

PERFORMING A LESS FRAGMENTED ARCHITECTURAL EDUCATION AND PRACTICE

EDITORS MARIA VOYATZAKI | CONSTANTIN SPIRIDONIDIS

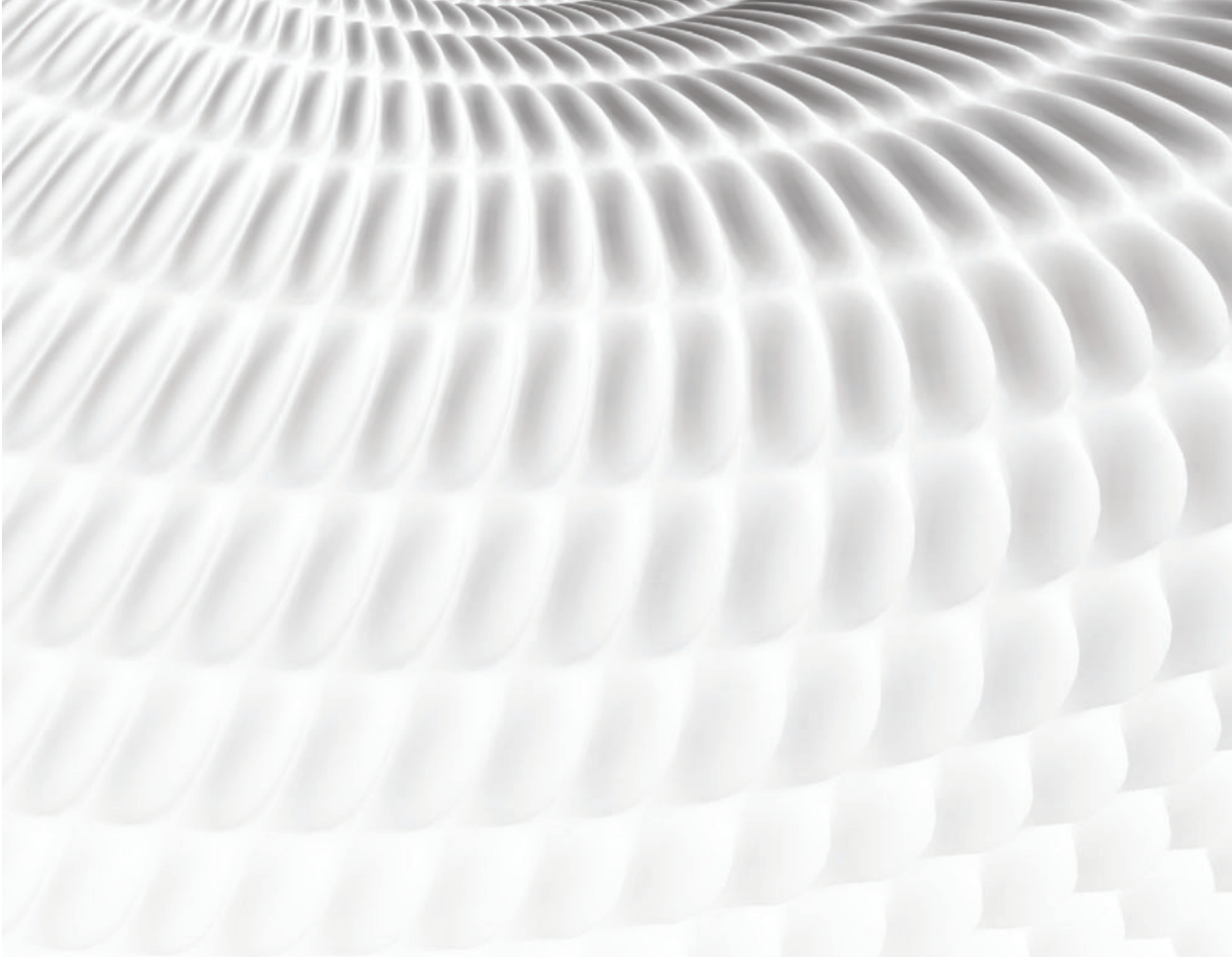
**European Network of Heads of Schools of Architecture
European Association for Architectural Education
Münster School of Architecture**

International Conference

Scaleless - Seamless
**Performing a less fragmented
architectural education and practice**

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Initiations

Scaleless - Seamless:

In quest for a less fragmented architecture education and practice

Change and the speed of change are the main, and at the same time, the least analysed and studied characteristics of the so-called digital era we are experiencing. Unexpected modifications of possibilities continuously affect the mental and operational landscape of our life, our capacities and the conditions in which our lives evolve. Rapid changes directly influence our social, financial, cultural and built environment and our conceptions about the human being and the world. The contemporary world is increasingly conceived as a global and systemic environment. A continuous environment structured upon an increasingly internationalized knowledge-based economy, upon the increasingly globalised consequences of local actions, conditions and facts, facilitated by the extremely powerful media and the extended applications of digital technology in all sectors of production, administration, education and consumption. This globally systemic - parametric understanding of the world is conceived as being structured upon parts which even if they obey to their own logics and rules, they are directly and permanently affected by the predictable and/or unpredictable changes occurring in the other parts. All our activities are profoundly influenced by this new condition of instability, fluidity and interdependence of various, very often, unpredictable parameters and factors, which rapidly transform our vision introducing us progressively to a globally systemic - parametric understanding of our position in the world.

In this unconventional and fluid environment of internationalized economy and information society architecture, as a cultural statement and manifestation of our life in space, seeks its new considerations. It is currently elaborating a redefinition or restructuring of a new framework of values and principles, knowledge, skills and competences, tools and means, priorities and preferences. It is developing a new culture, replacing values and priorities that nourished architecture for centuries. In this new culture, change and its operational expressions like adaptability, transformability and flexibility are replacing stability and solidity, experimentation is replacing already tested and secure solutions, customization is replacing standardization and metrics, variables are replacing constants and digital tools are replacing analogue representations.

All these changes go hand-in-hand with the extremely fast development of information technologies and digital tools supporting the process of simulation, representation and generation of architecture. These tools reflect a new conception of the world, a new conception of architecture that progressively distances itself from the human-centered understanding of architectural priorities nourished in the previous centuries, in favor of an ecosystemic and cosmic-centered understanding. The creation of architectural forms can be conceived now as similar to a genetic process directed by algorithmically codified information under the influence of a complex series of internal and external parameters. The new tools offer possibilities of architectural creation as no longer being conducted in a fragmented process but by a seamless one, where the representation of space becomes scaleless, and the transfer of infor-

mation between the parties involved in the design and the manufacturing process is seamless. At the same time a constant revision, adaption and inclusion of detailed information such as material properties and real-world data has the potential to make architectural creation dynamic and vigorous. All these changes are also accompanied by a seamless trans-disciplinary approach to architectural and urban space design, which promotes a new understanding of the generalist profile of the architect.

It is true that nowadays we are experiencing a progressive shift of the profile of the egotistic polymath architect established primarily by the modernist experience of architecture of the 20th century. This profile was based upon the capacity of the architect to transgress the increasingly separate professional realms of architecture, engineering, humanities, urbanism, landscape and interior design. Having a limited knowledge about each one of them the architect of modernism was charged to assure a top down prestigious role in the interdisciplinary design team conceived as the conductor of the orchestra. These days all the above-mentioned professional specializations are progressively launch algorithmic interpretations of their internal and external complexity of parameters. We can observe a tendency of this digitalized practice to demand its integration in a seamless digital collaborative enterprise to generate space with a holistic view of its performance. In this condition, the generalist architect is no longer the master builder of forms to be materialized with the synergy of the other specializations. He or she is rather the master builder of bottom up information composed by quasi-autonomous fragments provided by the different specializations from which the performative dynamic of the project emerges. He or she is rather the editor than the author of a book having to handle sufficient complexity to still have both the responsibility but also to enjoy the credit of the generated architectural creation.

In these new conditions the scaleless and the seamless appear as the two key pillars of the requested integration in contemporary architectural practice and education. They become its objectives and at the same time its values. Do the design and planning practices and construction industry respond to these new requests? Can the curricula of architectural schools escape from the dominance of fragmentation within their structure and the organisation of the modules and academic units? There is a paradox between the objectives of contemporary architectural education and those of contemporary architectural practice, the former subscribing more to fragmentation, the latter being more keen on integration.

The question arising is how we can organize architectural education in a way that will incorporate in our teaching the inseparable seamless and scaleless presence of a way of thinking about the form with a way of thinking of its materiality, its social and cultural representations, its environmental aspects, its urban references. We all accept the design studio as the melting pot of architectural knowledge but is it really the place where the seamless and the scaleless can be assured? How can the traditionally separate courses offered by departments and modules of architectural education institutions be redefined in order to assure the scaleless and the seamless?

As the seamless and the scaleless progressively are established as keywords in contemporary architectural thinking and creation, we can define different paths for their fur-

ther investigation. The first path is through design. How can we design the seamless and the scaleless? Which are the emerging challenges and potentials of digital tools to the direction of a more integrated design practice? Which are the limitations of these tools? Which are the new conceptions of design and creativity, which open new avenues to the potential of digital tools? In what way design methodology has to change in order to accommodate the seamless and scaleless, but at the same time avoid architectural designs to become mere materializations of available software features?

The second path could be through theoretical investigations. How can we theorise the seamless and the scaleless? Which are the common grounds on which we can ground the seamless and scaleless in architecture? How can Architecture learn from other domains of knowledge, e.g. automotive and aircraft technologies, BIM technologies, where integration is an essential part? What do the differences lie on? What pedagogies can best ensure the seamless and scaleless in teaching theory to architecture students?

A third possible path for the investigation of the seamless and scaleless is through building performance and building performativity. How can the way we design and materialise architecture be transformed by these possibilities in the future? To what extent do these new tools support the generalist role of the architect as an integrator and communicator, enforcing a more moderator type of role? What bridges can be established between design and fabrication in order to assure the seamless? How can the collaboration between academia and the building industry cooperate to ensure the seamless and scaleless?

This investigation can also be done through the scrutiny of the computation processes implemented to assure the seamless and scaleless. What are the contemporary outcomes in the research on the domain of digital tools for design and fabrication that can open up new possibilities in architecture practice and education? How can computation assure the seamless and scaleless in architecture education and practice?

As the education of the architect can assure the creative amalgamation of all the above-mentioned questions, it offers another interesting path to inspect the seamless and the scaleless. How can architectural education engage with these challenges and potentials? Which teaching methods and tools are necessary to overcome the fragmentation of educational organizational structures towards more integrated ones? What teaching modules can best enable the seamless and scaleless? What collaborations among teachers with different backgrounds can help in that direction?

Having as a background the spectrum of all these questions, the European Network of Heads of Schools of Architecture (ENHSA) and the European Association for Architectural Education (EAAE) in collaboration with the Departments of Digital Design and Building Construction of Muenster school of architecture invited teachers, researchers and practitioners to discuss potentials for the development of more integrated formats of education and practice. The Symposium was entitled 'Scaleless - Seamless? Performing a less fragmented architectural education and practice' and was hosted by msa | münster school of architecture from 15 to 17 November 2012. Its main aim was to give an overview of the practical implications of collaborative processes as well

as contemporary research in this field. Additionally, it presented cases of architectural design, construction and fabrication where information processing with digital tools played a crucial role in the design process at different scales. This way the event gave the possibility for a fruitful and creative exchange of experiences, views and practices, which could enrich our teaching and nourish our efforts for a more profound understanding and practice of contemporary architecture.

This volume contains all papers presented in the Symposium. With it ENHSA Thematic Network offers a useful academic material for thinking, inspiration, comparison, motivation and stimulation. Rarely can updated discussions of this type take place in architecture schools among staff. For this, the present material can be perceived, read and considered as a vehicle driving us to architectural ideas, which affect, influence or even direct contemporary architectural education. In the present dominance of media and information technologies, the access of our students to architectural innovation is fast and direct but in most cases superficial and incomprehensive. In order to encourage them to strive for innovation we need to develop and implement pedagogies, which will not merely invite them to study and follow examples of successful practice architectures they see in architecture journals and web sites. We need pedagogies, which will introduce them to the origins of the thinking processes through which these architectures have been generated and have been established as innovative; pedagogies which will encourage an inventive and creative “disobedience” to the established and will promote the necessity of thinking and doing things differently. The shift from a knowledge-based to a learners’-and-competences’-based education we are experiencing nowadays presupposes significant transformations in our educational practices and teaching strategies. In this new pedagogic approach learners must be exposed to and familiarized with the risk, the mistake, the experimental, the unknown, the uncertain, the unstable, the transformable. In these new priorities of the contemporary project to educate people, creativity and innovation appear to be not only fundamental competences to be assured by the learners but also significant values of their identity and profile. This volume is offered and can be read as a small step in this direction.

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Architectural
Operating Systems:
Prototypes
for Performative Design

As contemporary architects with ubiquitous digital technologies for information processing, design and fabrication, we have the capacity to maintain mathematical control of specific data sets and coordinates related to the construction of the built environment. But how can an architecture, engaging these precise technologies, become informed by processes that we cannot control in the same way? All architecture is, to some degree, in contact with its local climate at any given time, but an architecture that is more deeply permeated by and affects its local climates has a major impact both on the architectural design as well as conditions of social space, environment, economy, politics and the experience of architecture, cities and landscapes.

Research context

Permeability and energy-efficiency have been considered a contradiction, but a hermetically sealed architecture, as the architect Alejandro Zaera-Polo has pointed out [Zaera-Polo, 2008], is no longer the predominant solution. A gradual engagement with the surrounding atmosphere produces several important architectural possibilities at different micro- and macro-scales such as the filtering and exchange of air, light, moisture, and sound; exchanges between complementary programs and collective space, as well as architectural and economic possibilities for the program to swell and contract by engaging adjacent surfaces and exteriors.

The project discussed here, the Hydrophile Hydrodynamic Green Roof, address these questions in different ways. This project reconsiders the relationship between technology, energy and biological processes in architecture focusing on synthetic architectural systems informed by the formation, function or structure of biologically produced substances and processes. As a speculative series of artefacts and a speculative environment, the project uses and questions scientific results, "not to tell a great narrative of progress, but simply to explore the nature of the atmosphere in which we are all collectively attempting to survive." [Latour, 2003]. This work engages the possibility for architecture to act as a site where biotic and abiotic substances coalesce toward specific forms of architectural performance.

Hydrophile was produced as a collaboration between the design and research practices *servo stockholm* and *servo los angeles*. The project exemplifies the hybridization of technological and aesthetic performance in architecture. It presents alternative paths for an architectural design-based research that relies on the production of artefacts as a site for critical reflection and invention. The work investigates an emergent approach to design, ecology and digital fabrication in architecture. An emergent property of a system, in this context, is one that is not exclusive to any component of that system, but is nonetheless a feature of the system as a whole.

Testing and implementation through the production of artefacts such as large scale physical prototypes is imperative for this research. What is the role of an artefact in the design development process, how does it affect the design and research discussion, and how is it affected by the dialogue it engenders? These artefacts or prototypes are not primarily produced for solving problems and documenting different stages in the project, but in order to allow for the discussion, modulation and evaluation of the

project in dialogue with design research colleagues as well as partners and stakeholders from other disciplines, stimulating innovation [Speaks, 2002] [Runberger, 2008]. The Professor and Sociologist Bruno Latour has pointed out, that the sciences have expanded and transformed the world into a laboratory, where the envelope of the modernist laboratory of strict confines is pushed and permeated [Latour, 2003]. Design driven research or practice based research in architecture pushes the envelope of where architectural research is performed. The development of design artefacts and architectural environments for disciplinary and interdisciplinary dialogue, site specific experimentation engaging different social and environmental conditions and the use of the public exhibitions are all generative venues for architectural design research.

Methodologically the ongoing research project engages three different environments where the artefact has an important role for design research: the design studio, the exhibition and the built environment. These contexts produces different sorts of feedback and dialogue and thereby engender different kinds of knowledge, design knowledge that drives the processes.

The design studio is the workroom where members of the design team and collaborating partners, whether of disciplinary or interdisciplinary gathering, work with incremental modulations of the artefacts in response to the ongoing dialogue between team members. These design procedures entail both subtle articulations as well as larger design leaps. Educational researcher Jonas Ivarsson, who in his research on *Epistemic topologies: Arranging for advanced knowledge articulation* is following this particular research of the design collaboratives servo stockholm and servo los angeles, has pointed out, "Even the most preliminary findings suggest that a wide range of decisions, considerations, deliberations etc. necessarily surface in the interaction between the team members. The accountability structure is integral to the gestalt of the project. Consequently, singular design moves that cannot be communicated and motivated in relation to the larger whole tend not to survive in the iterative process. In this way the entire assemblage of enacted relevancies and preferences thus make up the unique features of this specific design collaborative." [Ivarsson, 2011].

By moving the artefact or artefacts out of the design studio, into the social climate of the exhibition, another set of responses emerge. The social context of exhibition and the event structure around it, have the capacity to generate *discourse* through assemblage and display of artefacts and through the *contextualization* of the work in panel discussions, seminars, exhibition catalogues and other publications. This feedback furthers the articulation of design as well as discourse. Letting the artefact or prototype oscillate between the design studio and the context of the exhibition, altering the proximity between these settings, provides a generative ground for design development. An incremental testing, prototyping, of different design phases of a larger ongoing research is made possible.

Of great significance in our research is the possibility to move the architectural experiment not only between the design studio and the exhibition, but into the built environment, exposing the prototype to weather and everyday use, becoming part of a larger infrastructure that constructs our social, urban and built environment. The

confines of the experiment; the design studio, the exhibition or the built environment, are thus continuously redefined and generate different climates for feedback and dialogue that cultivates the ongoing design, research and development.

Applied research

“Pure research is used in a field of pre-existing forms of knowledge – a discipline, while the aims of applied research go beyond the disciplinary classification, to the achievement of a certain type of performance.” [Zaera-Polo, 1998].

‘Pushing the envelope’ is the terminology the Professor of Architectural Theory and Criticism Sanford Kwinter once used to describe a particular strain of architectural practice. Practice in this context encompasses both the constellation of individuals forming the office as an entity but more importantly the repertoire of techniques through which that group operates and communicates. The practice Kwinter described was OMA and its propensity for transforming the disciplinary boundaries of architecture through embracing and amplifying certain protocols that would appear to originate outside of the discipline [Kwinter, 1996]. The technological metaphor he used, the ‘performance envelope,’ refers to an aircraft and the resilience of its design in the context of specific environmental factors. Pushing the envelope means taking the aircraft beyond its designated altitude or speed limits. This reflects one aspect of what we might call architectural performance. It implies that there are specific parameters within which the practice of architecture operates, that architecture in fact may have a speed limit. But what is the nature of this speed limit and where is it imposed? Within the realm of material, technological, geometric, programmatic, social, political or economic contingencies that inform both the design process and its end product?

Exceeding this architectural speed limit undoubtedly opens up new possibilities in the terrain of what the design theorist Michael Speaks calls ‘design intelligence.’ For a practice like OMA this might entail embracing certain generic spatial qualities (i.e. the relation between an elevator core and exterior building envelope) and intensifying them to an extent that new architectural qualities begin to emerge. Speaks differentiates between conventional practice and innovation by noting that, “While problem-solving works within a given paradigm to create new solutions to known problems, innovation risks working with existent but unknown conditions in order to discover opportunities that could not have been predicted in advance.” [Speaks, 2002]. This attitude privileges *how* practices work thereby affecting *what* they produce. Speaks uses the example of small, decentralized practices working with digital fabrication and communication technologies enabling them to rapidly prototype projects. In this way, they can test the capacities of a design proposal more quickly than larger offices that are engaging in full-scale building design and construction. One aspect then of exceeding the speed limit or ‘performance envelope’ of architecture relates to redefining the conventional set of problems as given and defining new areas for innovation.

Speaks’ concept of ‘design intelligence’ also ties in to recent debates on the nature of contemporary architectural practice that have identified a distinction between critical

vs. projective practices, aligning the former mode of practice with representation and the latter with performance (what something looks like as opposed to what it does). The design theorist Bob Somol, projecting a *performance* value of sorts into the discussion, casts the "affirmation of performance," as the primary alternative to the "negation of critical representation." [Somol, 2008]. He adopts J.L. Austin's, a philosopher of language, notion of the performative utterance or speech act whereby the saying of something alters the state of the world and creates a new set of relationships between people and things (as in the bequeathing of property). This differs fundamentally from what Austin refers to as a constative speech act - describing the world as it exists. Is the nature of architectural practice in fact as binary as these propositions would lead us to believe or is there the possibility of performance that hybridizes the what with the how of architecture?

A multivalent implementation of architectural performance, one that involves an agile negotiation between *imaging* and *performing* begins to surface in a specific strain of contemporary architectural production. Technology plays a crucial role in this equation as it invariably introduces certain propensities or biases into how we deal with material and informational regimes. Digital modeling and fabrication technologies, due to the fact that they enable specific contingencies or parameters to be staged as interdependent and enable iterative processes to be enacted, allow for performance to coalesce with product. As in the design intelligence described by Michael Speaks, the way of working influences what is produced. An example of this is what the architect Greg Lynn in his seminal book *Animate Form* refers to as a "numerically controlled multi-type that is flexible, mutable, and differential. This multi-type, or performance envelope, does not privilege a fixed type but instead models a series of relationships or expressions between a range of potentials." [Lynn, 1999]. Lynn contrasts this notion of flux with the static fixity of a timeless geometrical model as posited by architectural historian and theorist Colin Rowe in his book *Mathematics of the Ideal Villa* [Rowe, 1976]. Rowe's notion of fixed typologies linking the work of the architect Le Corbusier to underlying geometries in the work of Palladio can only be approximated by averaging away the differences between individual instances rather than exploiting these differences for their unique qualities. Lynn also cited the biologist D'Arcy Wentworth Thompson's delineation of 'flexible grids' or performance envelopes used in Thompson's research on "the comparison of related forms." [Lynn, 1999]. These envelopes consist of environmental factors (water temperature, local predators, etc.) that influence the morphological characteristics of various organisms, in other words *pressures* that are effective in shaping the organism. These factors are graphically mapped in relation to the organism as a projective mesh of influences. Lynn proposes that these flexible models can be used as generative processes in architecture.

The architectural critic Reyner Banham in his text "A Throw Away Aesthetic" from 1955 points out that the so called 'machine aesthetes' architects from the early 20th century, who strived for fixity or an *ideal*, at which to aim, had misunderstood the potentialities of industrialized production. For engineers, on the other hand, a norm or type is only stabilized for a moment, "the very opposite of an ideal, because it is a compromise between possible production and possible further development into a new and more desirable norm" or type [Banham, 1981]. In that sense, Banham already introduc-

es the possibility of feedback between design development and fabrication, putting design and production in close proximity. The process that Banham explains precedes contemporary use to rapidly prototype projects, agile to feedback mechanisms nourishing multiple directions of design development, innovation and fabrication, for the evaluation of design performance as well as technical performance.

The interest in designing with environmental factors that influence the performance of envelopes complicates the relationship between design and fabrication even further. Today's vegetation technologies for green roof systems, are often low in diversity and standardized into prefabricated planar mats, rolls and plug plants. This fixity is not ideal in a Banhamesque sense. To embrace the material entropic tendencies of organic substances suggests the experimentation of non standard strategies for the design, fabrication and assembly of a composite architecture constructed of both biotic and abiotic materials.

Performative design

Contrary to a linear design approach where technological processes are applied in the interest of the optimization and resolution of a design (basically solving pre-established problems); performative design embraces a *bi-directional* approach where technological processes are incorporated as drivers of design innovation. In order to refine the definition of performative design the following approaches can be considered. The first, *technological performance*, is related to the posing and resolution of specific technological problems through techniques designed with the agility to optimize performance. In this approach, value is derived from an awareness of the 'technology at work' as an operation. In technological performance, the processes and procedures become more important than the content they produce. The dome structures of Buckminster Fuller would be an example of this type of performance where the structure is adapted to be as lightweight as possible while maximizing structural efficiency. The outcome is a very regulated geometry that resists the differentiation that occupying the structure would inevitably introduce.

The second approach, *affective performance*, subsumes 'technology as a means' to a more extensive set of effects that are generated by it. As the digital paradigm has expanded in scope, moving beyond tools for the representation of space to encompass digital modes of design and fabrication in architecture, this coalescence of material and electronic systems begins to reformulate notions of materiality. Affective performance does not privilege the processes and procedures that govern it; rather the atmosphere that is generated by these procedures becomes significant.

Biotic and abiotic matter in architecture

The separation of the biotic and abiotic can be, and has historically been, considered in terms of entropy. *Construction = minus entropy*, was the equation formulated by the architect Kisho Kurokawa in his 1970 Capsule Declaration, the same year the artist Robert Rauschenberg demonstrated the extreme entropic consequences (structural failure) of the coexistence of dirt, a backhoe and an empty shed in his *Partially Buried*

Woodshed [Kurokawa, 1977]. Recent discussions centering on a more conscious and sustainable administration of energetic, material, and ecological resources in the production of habitable environments suggest a radical rethinking of the equation. A *potential imbalance* in the equation on an energetic level plays a critical role in the contemporary architectural discussion. The construction of architectural environments that have the capacity to embrace entropic tendencies, breeds a new strain of architecture. This architecture exploits the latent responsiveness of energetic exchanges - specifically the transfer of heat, moisture, sound and light through an architectural medium and their effects on more extensive ecologies - and ecosystems' alternative stable states [Beisner, 2003]. Balance is relevant in this work not only in terms of the statics of bodies in space but more importantly in an ecological sense. Imbalances become active as the impetus of design innovation. A composite approach to material and environmental architectural systems emerges in this work.

The Hydrophile Hydrodynamic Green Roof project considers the entropic potentials of the interaction between biotic and abiotic matter in architecture. It is a proposal for a bioscience innovation center with a hydrodynamic vegetated roof, located in the Albano region of Stockholm. The project operates at a building scale as well as at an urban scale and reconsiders the green roof typology in terms of architectural design and biodiversity enhancement. The extensive green roof, usually comprised of a thin horizontal substrate for growing vegetation and enabling rainwater runoff, is reconsidered in this project as a semi-intensive green roof - an occupiable zone characterized by immersive depth (Fig. 1). The section of the building incorporates a series of depressions and swells, instances where the vegetated roof permeates the interior exposing the tectonic and biotic qualities of the roofscape. The green roof is designed to be experienced from several vantage points: from above—walking amidst a dense landscape

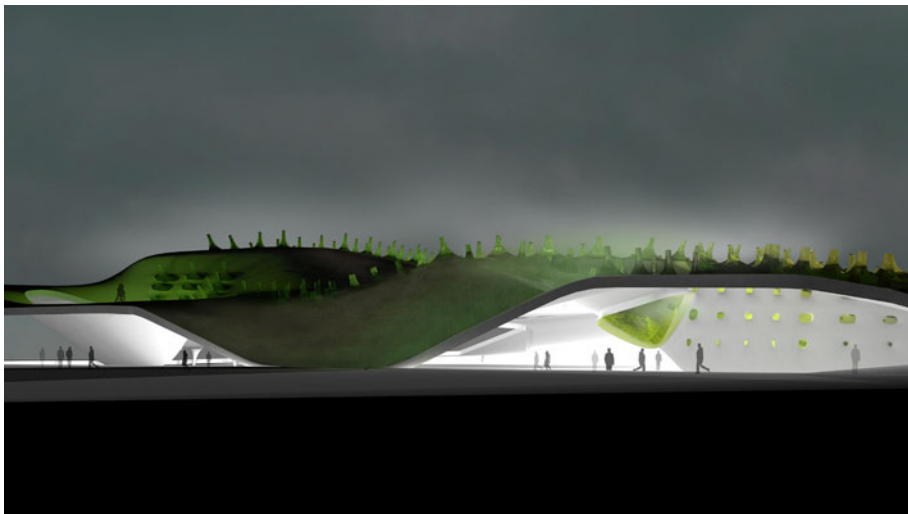


Fig. 1
Night view of hydrophile hydrodynamic green roof looking northwest showing entrance, and exhibition space.

of indigenous vegetation intertwined with protuberant forms that emit water, air or light; from below—as a suspended ceiling system that pulls down to close proximity with the floor; or from within – viewed through large apertures in the roof (Fig. 2).

The Hydrophile derives its name from the hydrodynamic properties found in the shell of the Namib Desert beetle. A coalescence between formal and material performance occurs at a micro scale in the shell of the beetle where hydrophilic—water attracting—and hydrophobic—water repelling—regions are interspersed to collect and direct the flow of water. In the Hydrophile prototype, this principle is applied on an architectural scale for the design of a *hydrodynamic* green roof system (Fig. 3). The hydrodynamic properties of a building system are exploited in this project for the cultivation of biotopes on and through a variegated roofscape augmented with systems for percolating water through soil substrates (Fig. 4). The material properties of ceramics with varying degrees of porosity are coupled with the protuberant roof morphology in order to perform as hydrophilic and hydrophobic agents, directing the flow of water for soil irrigation.

The main driving factors for the design of the Hydrophile building and its plant communities are the substrate thicknesses, substrate design, and the roof topography and geometry. The articulation of morphological and material properties generates structural and environmental performance and a gradient diversity of more or less inhabitable wet, dry and intermediate microclimates are produced. The roof topography is designed to direct water to depressions where large amounts can be stored to support wet meadows or fens. Substrate thickness is used to create vegetational gradients ranging from shrublands and meadows on thicker substrates, to dry meadows and heathland on thin substrate layers (Fig. 5-7). The plant material for the green roof is established through seeding, planting, and hay transfer from local similar habitats.

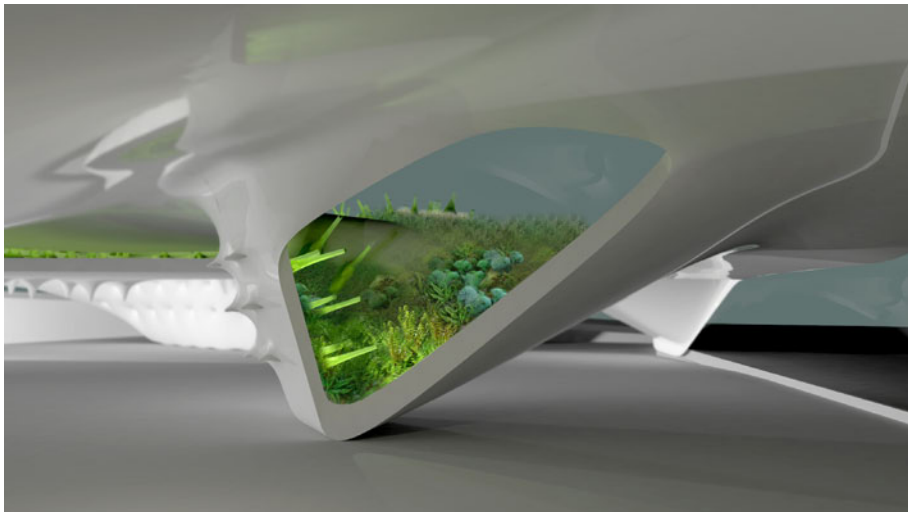


Fig. 2

View from entrance looking northeast toward mezzanine showing exterior vertical pocket garden.

Adaptive maintenance techniques including soil disturbance, haymaking, and water flow management are used to intentionally increase the production of entropy thereby supporting the biodiversity of indigenous plant and animal species (Fig. 8). This also stimulates changes in the texture, color, density, moisture levels and other material properties of the vegetated roof, informing and augmenting its tectonic qualities and architectural affect (Fig. 9-10).

Vernacular sod roof construction instigates varying degrees of imbalance between vegetal matter and the 'detail, decoration, and incident' of the building type. The entropic tendencies of landscape partially obliterate the features of the architecture. In the Hydrophile project the imbalance between biotic and abiotic properties is calibrated to produce specific qualities. The relationship between high and low resolu-

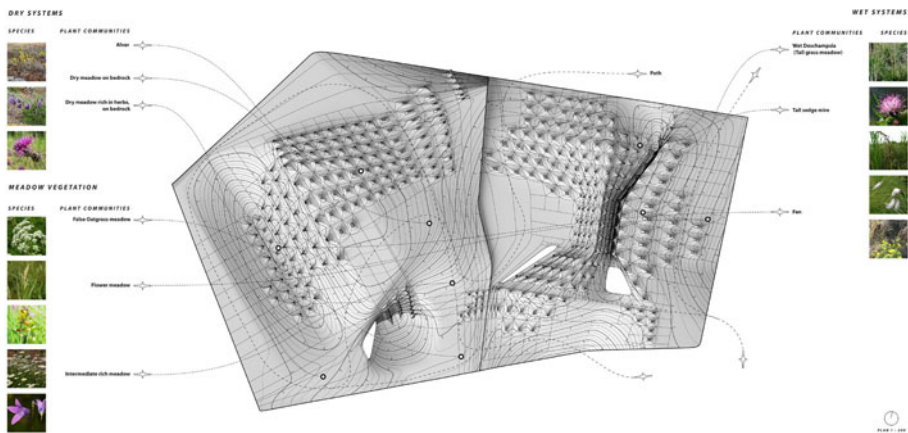


Fig. 3 Plan of hydrophile hydrodynamic green roof indicating location of protuberances for irrigation and ventilation, hydrodynamic flow diagram, contours, distribution of dry and wet systems and plant communities.

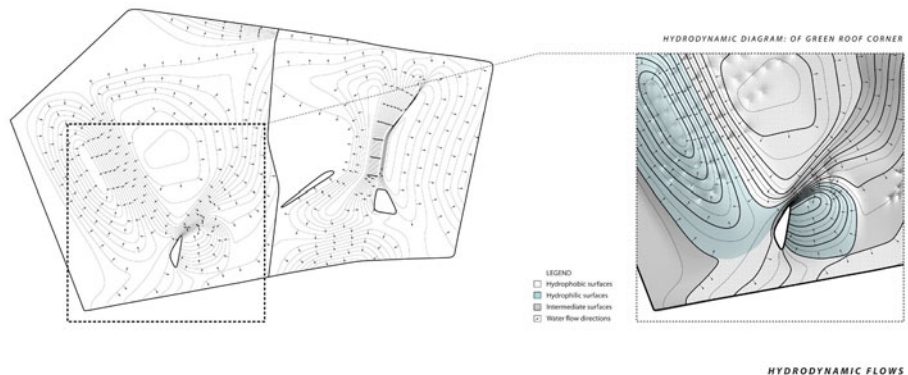


Fig. 4 Hydrodynamic flow diagram, and diagram outlining distribution of dry and wet systems.

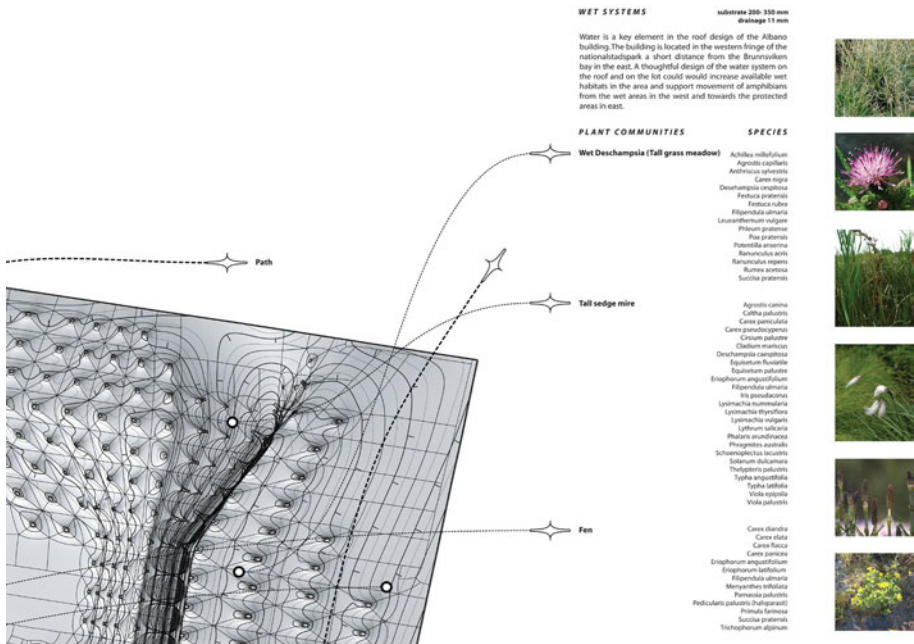


Fig. 7
 Detail plan of hydrophile hydrodynamic green roof indicating distribution of dry and wet systems and plant communities.

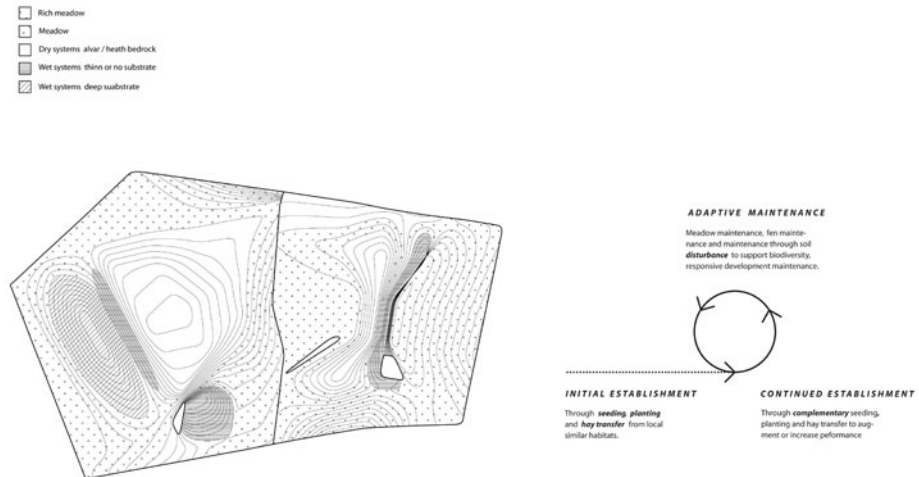


Fig. 8
 Diagram outlining adaptive maintenance cycles.

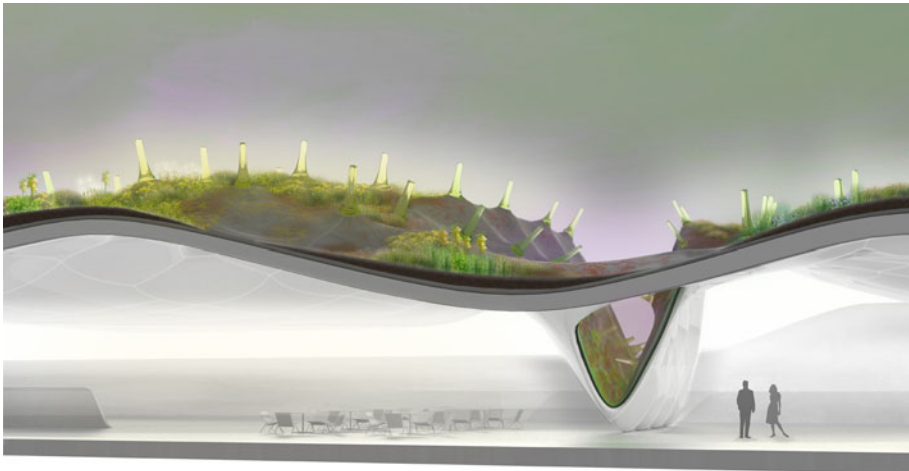
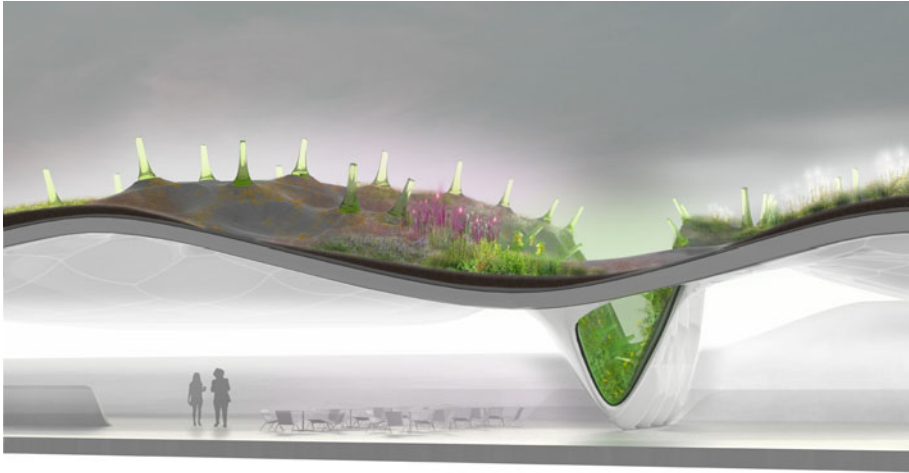


Fig. 9-10

Views of project showing changes in texture, color, and density of vegetation.

tion in the architecture is played out through the emergence and disappearance of articulations such as edge, contour and ridge in the slabs and apertures, producing varying degrees of definition and ambiguity across several scales in the project (Fig. 11). The Hydrophile project addresses a certain form of contextualism through the performance of indigenous vegetation from the cultivated grounds in the region (Fig. 12). The roofscape is incorporated into a system of urban green surfaces that provide important links for the migration of species, possibly supporting existing ecosystems, biotope structures and habitat networks and promoting biodiversity in the local environment (Fig. 13).

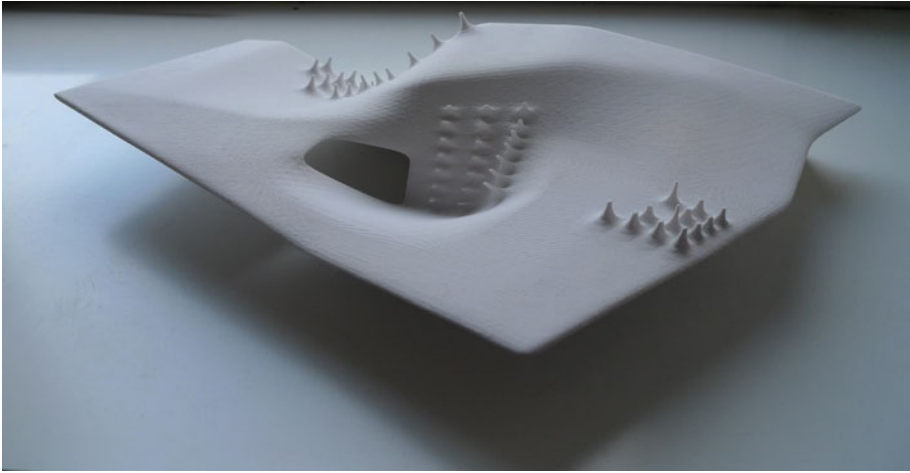


Fig. 11
Photograph of 3D print model.

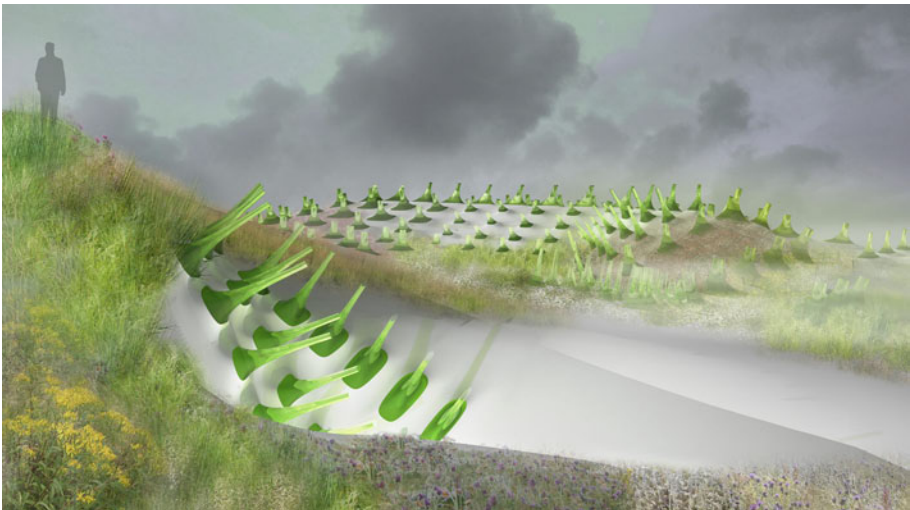


Fig. 12
View from west heath area of roof looking east toward meadow areas.

Surface logics

“Surfaces are the boundaries of matter, the interface between solid or liquid matter and gaseous elements or space.” [Burry, 2010]

The elusive relationship between the computational control of surface geometry, to produce architectural interiorities, volumes, apertures and structure (which gives the architecture a distinct shape), and the surface’s material capacity, as a differentially permeable thickness, to engage with the surrounding atmosphere, moisture levels,

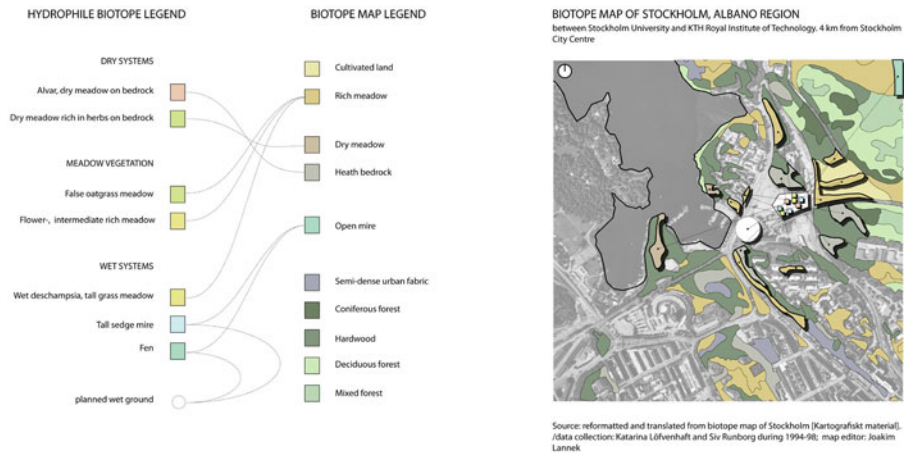


Fig. 13
Biotope map of Stockholm, Albano region.

substrates, dirt and vegetal matter, involves a shift from the precisely figured toward a more entropic state, occasionally obliterating the discrete identities of the surface. Through the manipulation of surface geometries, the schematic design phase of Hydrophile generated a series of interior volumes, mega pores or large scale pochés. Instead of the historical use of the word poché denoting the substance of building material, usually rendered as black on an architectural drawing, in the Hydrophile project a focus in the volumetric qualities of poché was developed. The interiority of the surface as inhabitable was developed, not only as an effect of structural and material thickness between spaces, but as a geometrically shaped space indicating the proximity of neighboring spaces. The buoyant quality of the auditorium floating in the space of the exhibition area and the deep depressions in the roof, producing vegetal poché (pocket gardens), experienced from the interior, creates a network of programmatic poché at a massing scale (Fig. 14).

A dramatic change in surface treatment has generated surface poché, pores and protruberances at a larger scale in current one-to-one scale prototyping phase. These are materialized with ceramic composites. Composite ceramic tests are conducted to study the fabrication technique using doublesided slip casting, the structural properties of composite ceramics, and the production of micro- and macro-scale porosity in the ceramics. One of the key ideas and central difficulties is to make this differential porosity work and enhance the containment and transportation of water, as well as the scaffolding or anchoring of vegetal root systems. The material section is developed to allow for the entropic tendencies of substrates and vegetal matter to permeate the macro-porous system of the top layer, possibly cracking it and forming a new composite matt of organic and synthetic matter. The middle layer with its capillary forces can perform as a reservoir of water for the biological material and the lower layer maintains structural integrity (Fig 15).

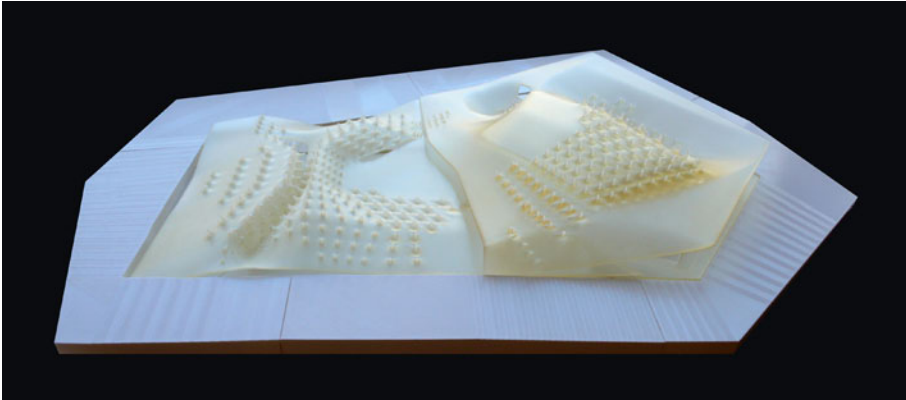


Fig. 14
Photograph of 3D print model.

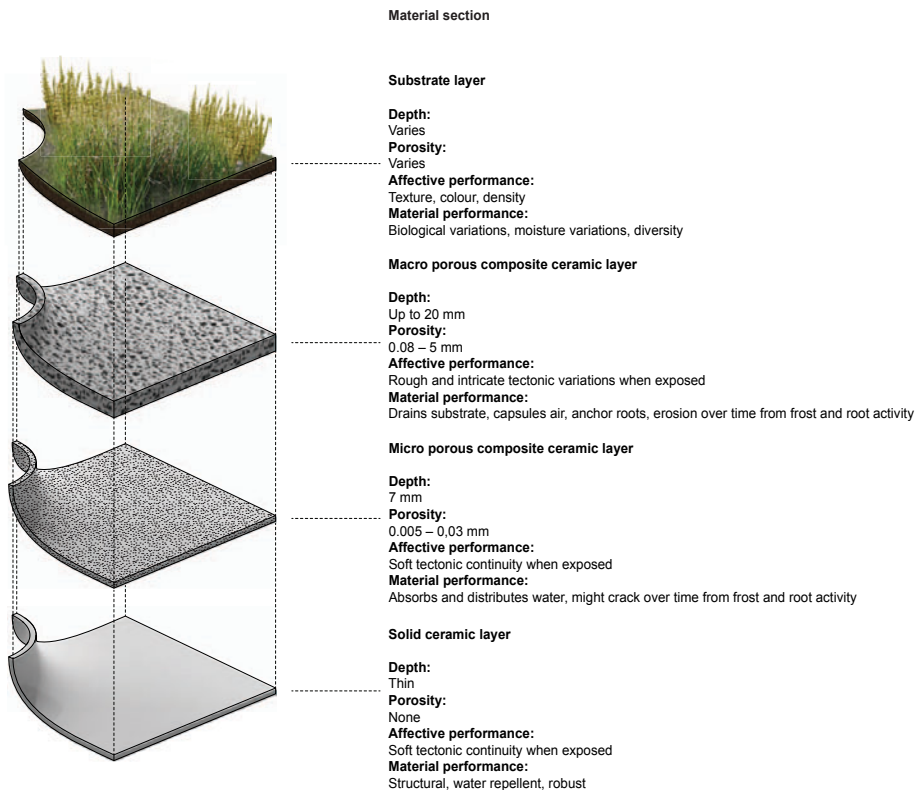


Fig. 15
Material section.

The Hydrophile hydrodynamic green roof is an architectural environment that actively embraces entropic tendencies. Energetic exchanges are activated on an environmental and urban scale in Hydrophile through its role as a constituent of an urban infrastructure and ecosystem that enables new patterns of occupancy (the migration of species) to emerge on and through its site. Vegetal matter performs as an integrated architectural material. This work speculates on the transmutation of the material aspects of architectural envelopes and conveys a contemporary obsession with the coexistence of tangible matter and more evanescent substance within architecture. In this work, the building, to some extent, obliterates its own identity and privileges sensation over image while at the same time it speaks to the issue of environmental performance. The architecture performs as an environmental filtering device. This kind of multivalent performance goes beyond both the indexical and the sensational by hybridizing these qualities. The ambition in exceeding architecture's speed limit or 'pushing the envelope' would be to allow various modes of performance to coexist and generate unanticipated architectural effects.

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Project credits

Hydrophile: Hydrodynamic Green Roof (2010 -)
Project Design - servo >> Design Research Partners - Ulrika Karlsson, Marcelyn Gow >> Design Research Team - Jonah Fritzell >> Ecologist and Green roof expert - Tobias Emilsson >> Funded by - Vetenskapsrådet (the Swedish Research Council), Konstnärskommittén (the Swedish Arts Grants Committee) >> Special Thanks: Jonas Ivarsson – Göteborgs Universitet, KTH School of Architecture, Hanna Erixon, Lars Marcus, William Mohline

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Material Generation
Materiality and Materialisation
as Active Drivers
in Design Computation

Computation, in its most basic meaning, refers to the processing of information. In this way, both machinic processes operating in the binary realm of the digital, as well as material processes operating in the complex domain of the physical can be considered computational. While there is a strong bias towards the former in contemporary design, sporadic investigations of the latter have also occurred in architecture. What is more rarely explored, though, is the territory where machine computation and material computation potentially overlap, where they not simply co-exist but intensely interact in the design process. Over the last ten years this has formed a central part of the design research we have pursued at the Architectural Association in London, at Harvard University and more recently at my new institute at Stuttgart University.

Contrary to most current uses of computational design and digital fabrication, this research is based on a synthesis of form, material, structure and performance in a process of integral materialisation, which finds its conceptual roots in the processes of becoming in nature: Natural morphogenesis, the process of individual growth and evolutionary development, derives the complex organisation, structure and shape of natural systems from the interaction of system intrinsic material capacities and external influences and forces. The resultant, astounding articulation, performative capacity and material resourcefulness, emerges through morphological differentiation, the summary process of each element's response and adaptation to its specific environment.

In contrast to the reciprocities characteristic for natural systems, the relation between information, formation and materialization in architecture is typically linear and, at least in regards to the genesis of form and its materialization, one-directional and hierarchical. Whereas material plays an active role in the generation of biological form, in architecture it is most commonly conceived as a passive receptor of otherwise determined shape. Since the Renaissance, the rising separation between the processes of design and making, and the subsequent development of representational design techniques based on descriptive geometry has led to an increasing division between design methods and subsequent processes of production, fabrication and assembly. Thus far the advent of widespread and increasingly ubiquitous use of machine computation in architecture had seemingly very little effect on this condition. While the integrative character of computational design has been extensively utilized for the inclusion of programmatic, structural, environmental or economic information, material information is hardly ever considered, let alone employed, as a generative driver in design. Especially in recent years one could witness a widening conceptual gap between the generation of form in the realm of the virtual and its manifestation in the physical world. Emblematic for this schism is the strange coactive development, where the ability of digital design to generate ever more exotic shapes has been facilitated and accelerated by the ability of digital fabrication to produce them. It seems as if the age-long predominance of shape-oriented representational design techniques based on explicit geometry and their direct, conceptual extension in most contemporary CAD packages still preconditions contemporary design thinking: Even in otherwise progressive and behavior-oriented design approaches materiality is still conceived as a passive property of shape and materiali-

zation understood as subordinate to the creation of form. Based on an understanding of form, material, structure, fabrication and assembly not as separate elements or processes, but rather as complex interrelations, our research focuses on a different approach to computational design and digital fabrication, one in which materialisation and computation is inherently and inseparably related. Algorithmic, computational design lends itself to such an integrative approach, as it allows encoding the characteristics and constraints of materialization in the physical world within the virtual processes of generative design.

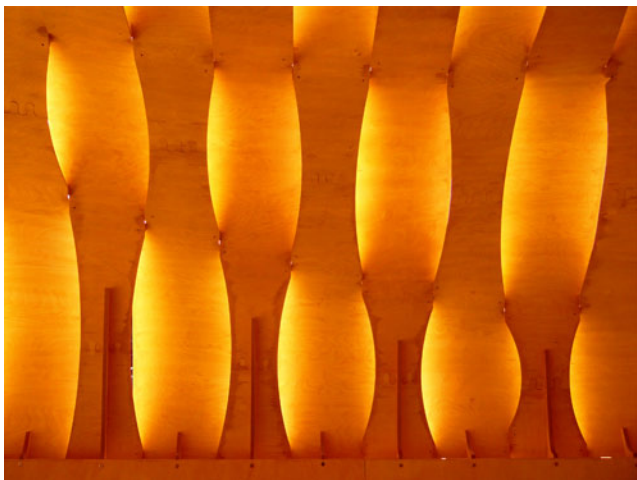
One challenge in the development materially-informed design computation is the difficulty of developing appropriate design methods capable of navigating the narrow path between under-determining material specificity, which leads to a lack of rigor and consequently operativeness, and over-constraining material properties and boundary conditions resulting in premature convergence and lack of exploratory potential. For the identification of an operative and explorative methodological spectrum two precursors of employing material computation in design may be relevant. One the one hand, Josef Albers material studies conducted as part of his *Vorkurs* at the Bauhaus in Dessau and later at the Black Mountain College in North Carolina, establishes a precedent for the possible enrichment of design processes through material experimentation. Albers rejected established processes of materialization based on professional craft knowledge, claiming that they stifle invention, and instead identified material behavior itself as a domain of creativity for developing new modes of construction and innovation in architecture. The material studies undertaken as a vital part of his courses were conceived not as scalar models or representations of cerebral constructs or ideas, but as temporary unfoldings of material behavior in space and time, which – in the designer’s hands – carry multiple possible futures and bear hitherto unsought of design potentialities. On the other hand, Frei Otto’s extensive series of experiments, conducted at his institute at the University of Stuttgart, of employing what he called *form finding* methods may serve as an example for the other end of the spectrum of an instrumental material-informed design approach. Otto investigated a vast number of different material systems, ranging from precisely defined structures such as grid shells to natural found granular substances such as sand, in order to study their self-forming capacities. He systematically studied their behavioral characteristics of finding a specific form, which manifests itself as the equilibrium state of external forces and internal restraints acting upon the system. His initial studies were an exploratory inquiry of possible points of departure for architectural design to develop through material behavior rather than the determination of form and space.

Considering the overlap between machine and material computation as a potential domain of architectural enquiry and technological innovation requires an interdisciplinary approach to design. In the morphogenetic process we have developed through a multitude of projects in collaboration with structural engineers, biomimetic engineers, computer scientists, material scientists and biologists, the relevant material properties together with the variability and constraints of digital fabrication processes can be encoded in the genotypic definition. Through this, any specific, phenotypic form or structure derived through subsequent processes of design computation re-

mains fully coherent with the logics and limits of materialization. Furthermore, the computational process of phenotypic development is informed through constant feedback with digital simulation, which allows responding to the heterogeneity of external forces, environmental influences and functional requirements. In this approach the architect utilizes computation for exploring the space of design possibilities defined by the logics and constraints of materialization, which opens up the possibility for a novel coherency of form, material, structure and function: a performative, morphological differentiation ready to be built, or in other words, an uncomplicated complexity. As examples for this, two design research projects – the ICD/ITKE Research Pavilion 2010 and ICD/ITKE Research Pavilion 2011, both collaborative undertakings of the Institute for Computational Design and the Institute of Building Structures and Structural Design at the University of Stuttgart - will be briefly explained in the following paragraphs. One concentrates on materiality and the related design space of material behavior, while the other focuses on materialization and the related machinic morphospaces.

Elastic bending is a familiar material behavior everyone has experienced. In structural engineering it is referred to as buckling and conventionally considered a failure mode, but, interestingly, it also has the capacity to increase structural performance and induce additional stability. However, due to the considerable technical and intellectual difficulties posed by a synchronous consideration of force, form and performance, there are only very few cases of elastically-bent architectures, as for example the Madan people's vernacular structures of bent reed bundles in Iraq, or the elastically formed wooden lattice shells by Frei Otto in Germany. The ICD/ITKE Research Pavilion 2010¹ aimed at further developing the often overlooked lineage of these bending-active structures, exploring their architectural potential through contemporary means of computational design, engineering and robotic manufacturing. The result is a novel bending-active structure, an intricate network of joint points and related force vectors that are spatially mediated by the elasticity of thin plywood lamellas. The system's delicate equilibrium state unfolds a unique architectural space while at the same time being extremely efficient with the employed material resources.

The initially planar plywood strips are manufactured with a 6-axis industrial robot and subsequently connected so that elastically bent and tensioned regions alternate along their length. The force that is locally stored in each bent region of the strip, and maintained by the corresponding tensioned region of the neighboring strip, greatly increases the structural capacity of the system. In order to prevent local points of concentrated bending moments, the locations of the joints between strips need to oscillate along the structure, resulting in a distinct articulation of the envelope, which is constructed from more than 500 geometrically unique parts. The combination of the pre-stress resulting from the elastic bending during the assembly process and the morphological differentiation of the joint locations enables a very lightweight and materially efficient system. The entire pavilion was constructed using only 6.5 millimeter thin birch plywood sheets that are at the same time spatial envelope and load bearing structure. Inside, the toroidal space can never be perceived in its entirety, leading to a surprising spatial depth that is further enhanced by the sequence of di-



ICD-ITKE ResearchPavilion (2010).

rect and indirect illumination resulting from the convex and concave undulations of the envelope, which finds its form as the equilibrium state of the embedded forces. The synthesis of material, form and performance enables a complex structure to be unfolded from an uncomplicated system, which is both economical to build and materially efficient, while at the same time providing an enriched semi-interior extension of the University's central public square.

Based on exactly the same everyday material, birch plywood, the next ICD/ITKE Research Pavilion 2011² shifted the focus from material behavior to the processes of materialization and the related exploration of machinic morphospaces as a generative design driver. The project aimed for uncovering potential areas of innovation specific to robotic fabrication yet also respecting traditional wood working acumen. Robotically fabricated finger joints were identified as particularly interesting: the computer-controlled production of differentiated finger joints that enables the connection of wood sheets of different thicknesses at different angles is currently unique to robotic wood fabrication. However, the high degree of kinematic freedom characteristic for the 7-axis robotic set-up opens up a vast space of possible plate morphologies, which begs the question how this space can be explored and populated in particular promising areas. One possibility is the employment of biomimetic design methods, where the theoretical machinic morphospace of fabricable plate structures is overlaid with and filtered through the morphospace of biological plate morphologies.

Finger joints do not require any additional mechanical fasteners or connection elements, and they are particularly versatile in withstanding shear forces. However, quite obviously, they are also relatively weak when exposed to tension or bending moments. This poses a considerable challenge for the design of finger-joint plate structures. In biology, plate structures as for example the plate skeleton of the sand dollar - a species of echinoids belonging to the order of Clypeasteroida - exist. Here, the individual calcite plates are also connected by finger-joint-like stereom projections, but nature has evolved highly performative plate morphologies that translate all acting forces into normal and shear stresses, and thus avoiding bending moments at the connections almost entirely. The related key morphological features of plate articulation, arrangement and topology were identified and translated into generative design rules. Informing these rules with the constraints and affordances of the robotic fabrication process resulted in a morphogenetic computational design tool capable of not only rapidly navigating the design space, but also deriving all required robot control code - a prerequisite for the production of the pavilion's 850 geometrically distinct plates with more than 100.000 individual finger joints. The possibility of using only extremely thin (6.5mm) plywood for all plates demonstrates the performative capacity of this integral skin structure. The resulting lightweight modular wood shell articulates both an interior space characterized by the perforation of the skin's inner layer required for assembly and an interstitial space emerging from the local separation of inner and outer envelope.

The next generation of architects will experience fundamental changes to the way architecture is produced and conceived. Integrative materialisation, both as a practical



ICD-ITKE ResearchPavilion (2011).

approach to design as well as an intellectual concept of architectural exploration, performative capacity and material resourcefulness, may provide a critical facet in facing the future challenges of the built environment.

This text is a combined, abbreviated summary of the the text MATERIAL (IN)FORMATION: COALESCENCES OF MACHINE AND MATERIAL COMPUTATION to be published in 2013.

Project Credits

1 ICD/ITKE Research Pavilion 2010:

ICD Institute for Computational Design (Prof. A. Menges).

ITKE Institute of Building Structures and Structural Design (Prof. J. Knippers).

M. Fleischmann, S. Schleicher, C. Robeller, J. Lienhard, D. D'Souza, K. Dierichs with A. Eisenhardt, M. Vollrath, K. Wächter, T. Irowetz, O.D. Krieg, Á. Mahmutovic, P. Meschendörfer, L. Möhler, M. Pelzer, K.Zerbe.

2 ICD/ITKE Research Pavilion 2011:

ICD Institute for Computational Design (Prof. A. Menges).

ITKE Institute of Building Structures and Structural Design (Prof. J. Knippers).

M. Gabler, R. La Magna, S. Reichert, T. Schwinn, F. Waimer with O.D. Krieg, B. Mihaylov, P. Brachat, B. Busch, S. Fahimian, C. Gegenheimer, N. Haberbosch, E. Kästle, Y.S. Kwon, H. Zhai.

Philippe Morel

EZCT Architecture & Design Research

Paris

France

**Some Geometries:
Polymorphic Geometries
and *Formal Language Games***

*"But to a sound judgment, the most abstract truth is the most practical.
Whenever a true theory appears, it will be its own evidence.
Its test is, that it will explain all phenomena"*
R. W. Emerson, *Nature*, 1836

*"Each creature is only a modification of the other;
the likeness in them is more than the difference,
and their radical law is one and the same"*
R. W. Emerson, *Nature*, 1836

"The sensitive space has nothing in common with the geometric space"
H. Poincaré, *On the Foundations of Geometry*, *The Monist*, January 1898.

When you are presented with an isolated word – such as the word geometry – your first reflex is to find its meaning. When you are given several terms, another reflex is to immediately search for the relationships that could exist between these terms. Thus, we could be tempted to look for the link between geometry, geography, effects and images. I believe this is what I did in my previous work on contemporary production and capitalism, where the vocabulary that I created around this subject – *integral capitalism, infocapitalism, technocapitalism, biocapitalism, or formal language games* – aims to clarify the nature of certain relationships. I will not, therefore, come back to the relationships between *geometry, geography, effects or images*, yet the study of the role of geometry as I envisage it in architecture contains implicitly, but partially, the study of what acts on it and what it influences.

It seems, therefore, that we are "programmed", so to speak, to study relationships between things and my use, above, of the word "reflex" applies perhaps to this "natural" character of our search for an explanation. This is what R. W. Emerson believes, asserting that "*Man is by nature an analogist and studies the relationships between all objects.*"¹ Now the study of relationships between objects is precisely what many mathematicians, philosophers and architects catch a glimpse of through their activities, it is even sometimes how they define the role of geometry. It is, of course, pointless to bring to mind the Platonic definitions of Le Corbusier on the relationship of objects, all the more so as few have generated such a vulgate within architectural discourse as these have (or perhaps despite them). Let us recall, however, the following affirmations.

The first is from H. Poincaré, "[...] *Thus by means of this reciprocity is defined a particular class of phenomena called displacements. The laws of these phenomena are the object of geometry.*"² The second is from R. W. Emerson "*Each creature is only a modification of the other.*"

The third and last is from F. Klein: "*But the fact of capital importance, is that the enumeration resulting from my point of view is complete; indeed it would be a result of comparatively little value to be able to deduct a number, however large, from special forms, if we could not prove that the method used exhausts the subject.*"³ Why come back to these three declarations, which have a great deal in common? Firstly, they introduce the key notions of recent contemporary architecture on morphogenesis, variation, the relationship between general (the whole) and particular (the element), secondly

they partially answer this question: "When we talk of geometry, what are we talking about?"

For H. Poincaré, the answer is relatively clear, geometry is the study of the laws which govern the displacements and transformations of objects. When it is only a question of displacements, that is to say the movement of an object which is not subject to a transformation at the same time, this is Euclidean geometry, but when the object is deformed to the extent that it is displaced, this is non-Euclidean geometry. Let us imagine with H. Poincaré a world full of differences in temperature and individuals linked to these differences, and so *"If to us geometry is only the study of the laws according to which invariable solids move, to these imaginary beings it will be the study of the laws of motion of solids deformed by the differences of temperature alluded to."*⁴ We could object that also in our world bodies dilate, *"Also experience variations of form and volume due to differences of temperature."* This is true, *"But in laying the foundations of geometry we neglect these variations; for besides being but small they are irregular, and consequently appear to us to be accidental."* For H. Poincaré, geometry is a study of the laws of displacement and/or transformation and because these are laws and not simple isolated observations, they imply regularity. What geometry contains by definition is to be a means of action, because from an element A and a relationship f we are able to foresee the result of the application of f on A, we are in a position to make a practical application from every breakthrough in pure science (we will later look at the possibilities of applied mathematics). What we are concerned with now is thus to know what is hiding behind the use of the term geometry in architecture and what is hiding there in the first place is not linked to our will but to the nature of the object manipulated. We have seen that if one carries out a rotation of a given angle on an undeformable object, this is Euclidean geometry, carrying out the same rotation whilst deforming the object and we are beyond Euclidean geometry. Because contemporary architecture carries out a large majority of operations of the second kind, we call it "non-Euclidean architecture". But are these the only distinctions that we can make? Indeed, how is such a rotation carried out, is it the result of an algorithm, is it the result of a physical displacement, is the object in question physical or is it simply implemented on a computer screen? Just one of these questions is enough to bring about a flood of new questions, we will therefore only ask some of them, but this approach is part of what I call a "local epistemology" for computational architecture. This epistemology is necessary for all "rigorous theorization" of contemporary architecture although it is not sufficient. It has its place within more global thought on the status of this architecture within a world which itself increasingly produces and is produced by calculations.

Alternative mathematics (Greg Lynn) and polyformalism

In *New Variations on the Rowe Complex* (ANY 7/8, 1994), G. Lynn makes a critique of the transcendental idealism of the first C. Rowe in favor of *"[...] an alternative mathematics of form; a formalism that is not reducible to ideal villas or other fixed types but in its essence freely differentiated"*. This critique is targeted not at C. Rowe (who himself rejected his initial analyses) but the first wave of computational architecture and its humanist combinatorics operated from a directory of already tested forms. G. Lynn's critique has in fact opened up many new paths but I would like to come back to it

to deal with the new formalism which it puts forward as *polyformalism*⁵. In concrete terms, this polyformalism concerns the multiplicity of models which are at play in any computational process and whose analysis remains to be made. An example of this is the current modeling of a plant which brings into play different mathematical models, different branches of knowledge etc. and not just one model (for example the algorithmical model of Lindenmayer) or a single equation (for example a differential equation as used in an analogical manner by D'Arcy Thompson at the beginning of the 20th century). It is this polyformalism that I introduced in architecture without naming it in *Notes on Computational Architecture* when I mentioned the necessity to add to all geometrical description of the form at least an algorithmic description (G. Lynn: "*As geometry is immanent to any architectural interpretation, even a displaced relationship between form and formalism must pass through a geometric description,*"⁶). I could also add this on the subject of polyformalism: if the new category of geometry that G. Lynn talks about through Husserl, a geometry which is "*inexact but nonetheless rigorous*" based on methodical ranking (*subtraction*) or on variation, which itself is based on "*alterations of deformation*" then compared by sensitive intuition either on the "*iterative reduction*" what place within the global process do these very iteration, alteration and deformation or sensitive intuition have, when these elements are considered as new models external to the initial geometric model? But before polyformalism, let us broach the question of architectural idealism with relation to the notion of the mathematical ideal.

That which G. Lynn introduces through Husserl from a philosophical viewpoint can be considered from a mathematical viewpoint as a theory of approximation, such a theory supposing a certain number of models with real differences. I will not return to the fact that an approximation can end in a circle but not to the "circle" object defined by its canonical equation since the aim followed by G. Lynn and by myself is to avoid resorting to such ideal entities, but what is this ideal anyway? It appears to me that we must first of all distinguish between the ideal of mathematical reasoning and the ideal of our representations (of our perception of what is ideal). This is what a mathematician such as H. Poincaré demonstrates and for whom there is no correspondence between these situations: "*Geometry in reality, it is not concerned with natural solids: its object is certain ideal solids, absolutely invariable, which are but a greatly simplified and very remote image of them.*" Within a Euclidean geometry, the ideal solids could thus be taken amongst the five Platonic solids – a cube or a tetrahedron – but such a thing as an ideal Platonic solid exists only in our minds, and the infinity of the other possible geometries – non-Euclidean – even opens up the path to the infinity of the corresponding ideals. Therefore, if geometry is not concerned with "*natural solids*" but with "*certain ideal solids*", the latter remaining transcendent and not subject to contingencies – historical or other – nothing implies that transcendence and ideals are mechanically and automatically linked to any sort of reality, a reality which of course is not necessarily physical but which can be a reality of ideas. It is the abuse of confidence in such a link that is revealed by C. Rowe rather than the abusive association between ideal and transcendence as demonstrated by G. Lynn, "*If the differences between the pairs of villas (Palladians) are marked as an outward sign of constructive, cultural or spatial practices of a given period in history. The underlying geometric proportions which emerge are eternal.*" If eternity of a "*natural, architectural kind*" is due to the fact

that it “refers to antiquity, where for the first time an exact geometry became visible,” it is also due to the fact that this exact geometry had its equivalent somewhere in Nature. The architectural order resulting from the mathematical order is only “natural” because this mathematical order was “natural” before it. The transcendental idealism of such as C. Rowe is therefore not, strictly speaking, idealism, but a realism in the sense that we can talk of a *realism of ideas*. If we observe the nature of the ideal in the philosophy of H. Poincaré it is completely different as we have seen, there is a separation between the natural solids and their “simplified and very remote image of them”. It is therefore only in appearance for Poincaré as for the first C. Rowe that the ideal does not escape reality. “If, then, there were no solid bodies in nature there would be no geometry.”⁷ In fact, if the ideal exists somewhere it is neither in the physical nature of objects nor in the intelligible nature of the ideas. “The concept of these ideal bodies is entirely mental.”⁸ Poincaré’s point of view allows him to relativize all forms of mathematical truth without disavowing the truth itself since there is no Truth, but a succession of partial truths, the value of such or such a truth resulting to some extent from its value of use “as truth”. Thus, it is possible for him to affirm at the same time that “ [...] we are anxious to arrive at geometric axioms which are rigorously and always true [...]” that “One geometry cannot be more true than another; it can only be more convenient,”⁹ and that without the least form of truth there would only remain a set of beliefs, “Here is the apparent diurnal movement of the stars, and the diurnal movement of other celestial bodies and the flattening of the earth, the rotation of Foucault’s pendulum, the gyration of cyclones, trade winds, what else? For the Ptolemaic, all these phenomena are not linked; for the Copernican they are brought about by the same cause. By saying that the Earth turns, I am stating that all these phenomena have an intimate relationship, and this is true [...]”¹⁰ Poincaré therefore introduces a conception of mathematics from the perspective of linguistic pragmatics with its own rules of translation, “[...] We have fixed rules which permit us to translate the French enunciations into German, and inversely. It is for that that grammars and dictionaries have been made. There are also fixed rules for translating the Euclidean language into the non-Euclidean language, or, if there aren’t we could do it.”¹¹ Thus, even to go so far as describing the “fantastic worlds” of non-Euclidean geometry, Poincaré could have “required no language other than that of ordinary geometry.”¹² In the multiplicity of geometric language games possible, he only retains the possibility of choosing the “most convenient” “[...] Is not our Euclidean geometry in itself only a kind of convention of language? Mechanical facts might be enunciated with reference to a non-Euclidean space which would be less convenient but quite as legitimate as our ordinary space; the enunciation would become more complicated, but it still would be possible.”¹³

Poincaré informs us, from a distance, of our own practice of contemporary architecture not by bringing into line the ideal (as a “mental image” of the mathematical truth) or a critique of its abusive moral extrapolation, but by the recognition of a multiplicity of new ideas. Each new geometry simply has the abstract and perfect object that corresponds to it and without which it would no longer be a science but a chaotic, accidental and temporary analysis, and I believe that without a precise equivalent of this ideal in Poincaré’s sense, architecture – although at the best it can only be rigorous without ever being a science – would not go very far either. The ideal consists therefore in a recognition of a foundation possible for all disciplines which allows us

to progress in knowledge but on which there is no point lingering if we want to avoid sliding definitely into ontology, like Husserl and his “Cartesian meditations”. This is why even amongst the most “pure” scientists, others like Poincaré make do with putting an end to the problem of foundation and reality as “*metaphysical*”.¹⁴ “*If we examine the structure of science more attentively, we will soon get this idea firmly fixed in our mind that we find in it a dangerously weak point – namely, its very foundations.*”¹⁵ Unlike Husserl, Poincaré indicated the path to a form of knowledge finally purged of all ontology, “*[...] Not only science cannot teach us the nature of things; but nothing is capable of teaching it to us and if any god knew it, he could not find words to express it.*”¹⁶ It is astounding to see the echo of such an affirmation in the philosophy of Wittgenstein, but also to what extent the near totality of the “general philosophy” (that which does not deal with local and disciplinary questions, for example concepts proper to the mathematical disciplinary itself, to physics etc.) of the sciences of Poincaré, which are usually close to Kant, finds antecedents in the Nietzschean philosophy, “*‘Explanation’ is what we call it: but it is “description” that distinguishes us from older stages of knowledge and science. Our descriptions are better—we do not explain any more than our predecessors. We have uncovered a manifold one-after-another where the naive man and inquirer of older cultures saw only two separate things, “cause” and “effect” as the saying goes; but we have merely perfected the image of becoming without reaching beyond the image or behind it.*”¹⁷ We will come back to Nietzsche later when we bring up the question of the continuum/discreet. In any case, the truth – which does not exist – remains the aim of this scientific activity (“*the search for the truth must be the only aim of our activity, it is the only end that is worthy of it.*”), but contrary to that which is believed in all theoretical speculation in the style of Colin Rowe (and here I include all forms of “computational” explanation of the universe as they appear today, which are based on cellular automata etc. and not on sections of gold) we are not approaching a real existence of truth as we reach the mathematical ideal, it is certain that only a fast analysis leads to such a shortcut. However, what is less certain, and the explanation for which could be an intimate need for certainty as much as anything else, is to know why C. Rowe was able to choose, if only for an instant, the most conventional philosophical position when bringing architecture closer to science: giving architecture the certainty of science, since “*scientific truth is unassailable [...]*”¹⁸ But “*to the superficial observer scientific truth is unassailable [...]*”.

Language games, approximation and industrialization

Not only are we not bordering on a real existence of truth as we reach the mathematical ideal, but we become distanced from it: “*[...] But we must not imagine that the science of mathematics has attained to absolute exactness without making any sacrifice. What it has gained in exactness it has lost in objectivity. It is by withdrawing from reality that it has acquired this perfect purity. We can now move freely over its whole domain, which formerly bristled with obstacles. But these obstacles have not disappeared; they have only been removed to the frontier, and will have to be conquered again if we wish to cross the frontier and penetrate into the realms of practice.*”¹⁹

This inescapable distancing between reality and the ideals to which they are supposed to correspond, is visible in the polemic which opposes Poincaré to Russell with-

in the two great trends in mathematical philosophy at the end of the 19th century, intuitionism (synthetic) – the qualifier intuitionism is more relevant to the position that Brouwer will take, Poincaré having perhaps initiated it by “conventionalism” – and logicism (analytical): *“the scientists of both schools have opposing mental tendencies; those who I called pragmatists are idealists, the Cantorians are realists.”*²⁰ H. Poincaré sets the combat of the ideals (certain ideals are effectively ideals whilst the others have to correspond to a *reality*), against the pragmatics of the geometric constructions which will increasingly become linguistic pragmatics. Now the latter is of the greatest concern to us, it could even be one of the most fundamental transformations of contemporary science, linked to the nature of scientific disciplines, to the nature of our theoretical constructions but also to the manner in which contemporary science transforms the whole of society, from the labor market to the urban settlement. I cannot develop here that which seems to be a strange shortcut but the intimate coherence that there is, for example, between a new human territorial settlement and the possibility to exchange mathematical models between computers cannot be ignored, as this coherence makes the majority of traditional, urban analyses (often spatial and sociological) futile and inoffensive. Linguistic pragmatics therefore exist for mathematics which must apply to something, in fact to reality. But Poincaré pointed out that when moving to practice, things risk getting a little complicated “[...] *But these obstacles have not disappeared; they have only been removed to the frontier, and will have to be conquered again if we wish to cross the frontier and penetrate into the realms of practice.*” It is therefore a question of developing a new theoretical arsenal, especially developed and adapted, to bring pure mathematics to their application, as we shall see.

Similarly there are for Poincaré two opposing trends in mathematical philosophy, and *“it seems that these trends are not about to converge,”*²¹ there are two *“opposing directions”* in which mathematicians can move, the first – “self-referential” – veers towards the inside, the second towards the outside. *“In one sense mathematics must return upon itself and that is useful, for in returning upon itself it goes back to the study of the human mind which has created it rather than to those creations which borrow the least bit from the external world. That is why certain mathematical speculations are useful, such as those whose aim is the study of postulates, of unusual geometries, of functions having peculiar values. [...] But it is to the opposite side—the side of nature—against which we must direct the main corps of our army.”*²² The majority of this army, is what we know today with the generalization of the figure of the researcher who gradually wipes out the figure of the engineer who was a main preoccupation for the avant-gardes of the early 20th century. Without entering into a methodical description of the science of the engineer, I believe that where the engineer, in the most traditional sense, methodically applies a knowledge, which is amongst other things mathematical – the mathematics being strictly speaking “applied” – the researcher is constantly enriching this *applied mathematical science* by an activity which in the end differs above all from that of the “pure” mathematician by the nature of the topic studied. This is what characterizes information science populated by researchers, even though these sciences would know few fundamental results compared to mathematics, or even though they would only be perceived by some as an application of pure mathematics (logic, complexity etc.).²³ But although mathematics as a whole is divided into two branches, pure and applied, what is to be said about our concern, geometry? Can an understanding of this sepa-

ration for geometry, or rather for the geometries help us to define the architectural use of the word geometry? Can it help us to understand this transformation which is the “industrialization of geometry” associated with its informational use, its “algebrization”? For of course there is nothing geometric, in the usual sense, in a computer, there are merely representations of elements with diverse geometric characteristics which appear on a screen and which, besides, might never have existed.

Let us therefore consider the problem of idealism (in fact the realism of ideas) of C. Rowe, dealt with not from G. Lynn’s philosophical viewpoint but thanks to geometrical pluralism itself, and let us consider our approach as more advantageous for the following reasons:

1) Contrary to the critique of G. Lynn which suggests replacing an architectural formalism that has become uniquely ideological by another formalism which runs exactly the same risk, a critique based on the intrinsic pluralism of contemporary geometry applies to all new ideal formalism; for example to the architectural formalism linked to the generalized use of geometry of Bézier within CAGD software (Computer Aided Geometrical Design). 2) An analysis which is based on a polyformalism leading to the elaboration of “formal language games” allows us precisely to draw up a “linguistic” critique, a critique which appears to me to have a greater potential for architecture than that of the formal critique. 3) Polyformalism is the “natural” state of all CAGD software and we can all confirm the weakness of software which only integrates a limited number of models. A clear analysis of the role of software in contemporary architecture is in part linked to the analysis of the models that they integrate. And what are these models and how are they integrated? How was it possible to embed in a computer the different geometries that we know? How do even the most traditional objects appear on a screen, when for example, to quote G. Lynn himself, “*The mathematics of the ideal villa seems to be equal to 0 and 1*”²⁴? It seems that all this is possible for five reasons. The first is a theoretical and mathematical possibility of repeating facts, the second is linked to the linguistic nature of geometry and its arithmetization, the third is linked to the possibilities, within the same computer of creating dialogue with mathematical models thanks to simulation, the fourth is the development begun in the 19th century within the very mathematical science of new types of knowledge around questions of approximation, the fifth is linked to nature and the role of exactness in all mathematical application.

Repetition

Let us begin by the “repeatability” characterized in two ways. First of all it is the only fundamental and natural characteristic of mathematical knowledge insofar as it is not related to any experience and insofar as it seems to be logged in our minds. Repeatability is this pure abstract possibility to add an element to a list, to a series. To carry out $1+1$, then $1+1+1$ etc. This possibility – and its generalization for eventual demonstrations by recurrence – seems to be, following the title of a chapter of *Science and Hypothesis*, “*the (very) nature of mathematical reasoning*”. As for the integer on which it is based, for Poincaré it is “*the only natural object of mathematical thought*”²⁵ and, for the epistemologist and analyst of H. Poincaré’s philosophy, A. F. Schmid, “*the translation, in mathematical terms, of our faculty to repeat an operation – more specifically that*

of successor.”²⁶ Something therefore exists which is the recurrence and which by definition allows us to foresee the facts, being “[...] *the affirmation of the power of the mind which is capable of imagining the indefinite repetition of the same act as soon as this act is possible.*” According to Poincaré, it also allows us to increase our knowledge as this recurrence (in fact the induction) allows us to obtain, as output, more than the simple sum of the input, hence more than a simple mechanical (analytical) accumulation of knowledge, “*The analytical process ‘by construction’ does not compel us to [...] descend, but it leaves us at the same level.*”²⁷ Here, this is more of a philosophical than mathematical question, which Poincaré recognizes, “*The very possibility of mathematical science seems an insoluble contradiction. If this science is only deductive in appearance, from whence is derived that perfect rigor which is challenged by none? If, on the contrary, all the propositions which it enunciates may be derived in order by the rules of formal logic, how is it that mathematics is not reduced to a gigantic tautology?*”²⁸

Thus, the first characterization of “repeatability” is philosophical, but it is another repeatability which will concretely allow the transfer from a “craft of applied geometry” to the industrialization of all geometry. This repeatability, exclusively mathematical this time, should be defined following precise criteria as “*reasoning formed from an uncountable sequence of propositions and syllogisms, what can this be? How can it be represented? Perhaps we should be content with the reassurance that we will never meet any contradiction; never significant at the end of a finite period of time, however long; but we would not have the certainty when it is a question of a time later than the end of eternity.*”²⁹ How can one effectively be sure, ad infinitum, of not meeting any contradictions? Precisely by putting this *infinitum* and the continuum which accompanies it to one side to “make do” with the finite and the discrete. This is what Turing did, after putting an end indirectly, to the question of Poincaré, when he demonstrated the undecidability of the general halting problem of Turing machines. “*It will seem,*” Turing explains in *Computing Machinery and Intelligence* “*that given the initial state of the machine and the input signals it is always possible to predict all future states. This is reminiscent of Laplace’s view that from the complete state of the universe at one moment of time, as described by the positions and velocities of all particles, it should be possible to predict all future states. The prediction which we are considering is, however, rather nearer to practicability than that considered by Laplace. The system of the “universe as a whole” is such that quite small errors in the initial conditions can have an overwhelming effect at a later time.*” Poincaré would certainly not have contested this last sentence, nor that which Turing says of his own machines, these “*discrete-state machines*”, “*machines which move by sudden jumps from one quite definite state to another,*” (like the addition of integers by recurrence that Poincaré uses as an example of mathematical reasoning). “*These states are sufficiently different for the possibility of confusion between them to be ignored. Strictly speaking there are no such machines. Everything really moves continuously. But there are many kinds of machine which can profitably be thought of as being discrete-state machines.*”³⁰ Poincaré and Turing would have agreed at least on one point, there is on the one hand continuum and on the other the discrete. In reality they would even have agreed with many other thinkers, so much is this separation at the heart of the majority of scientific or philosophical thought, thus with Nietzsche who one would hardly expect to give serious thought to questions of science, to the extent that posterity has presented him as a “moralist” and a “culturalist”. “*Cause and effect: such a duality probably never ex-*

ists; in truth we are confronted by a continuum out of which we isolate a couple of pieces, just as we perceive motion only as isolated points and then infer it without ever actually seeing it.”³¹ There is therefore a conceptual possibility of envisaging repetition, that is induction, there is a mathematical possibility, it is the “discrete-state machine”. It is the latter more than the former, which will ensure that all thoughts are “*potentially mechanizable*” – a problem which is at the heart of the research of mathematicians and philosophers of the “*formalist-linguistic turn*” – becoming “*really mechanizable*”. But what can we say, from the point of view of thought – hence also of architectural thought – of this mechanical character? What can we say here that would be valid for every common computer as we know and use them? For Poincaré, such a computer cannot lead to *original production* but only to *reproduction* as no result allowed by the computer is anything other than the result of a succession of syllogisms, which is effectively true from a mathematical point of view. “*Logic and intuition have each their necessary role. Each is indispensable. Logic, which alone can give certainty, is the instrument of demonstration; intuition is the instrument of invention.*”³² This clear separation seems to tell me more about contemporary architecture than the majority of existing architectural analysis. If the computer *creates nothing*, it would therefore be necessary to insert in it a series of external events, and it is to this extent that architecture (or art) always reappears in its most limited light: as *invention*. Now the issue in this text is simply to make it a privileged form of analysis, the highest form to which we have access.

Traditionalists will therefore insert in the machine subjectivity, their ideas, their personal opinions. But the architect, like “*the painter, it’s everything (I mean the major painter or at least the authentic painter). He does not cease (he supposes) to empty the world of any particular view; his own views amongst others. He only wishes – but it’s a strong wish – that this world beneath his hands would awake and reveal itself.*”³³

An architect that is apparently less of a traditionalist will try to recover, by non-human procedures, the intuition lost in the logico-mathematic analysis and in formalization. He will look therefore to cellular automata, to emerging processes (not as mathematical facts, which would of course be productive, but as a curiosity, as a “*novelty*”), to the vitalist-organic analogy or to chance. Now, such an architect is just as much a traditionalist as the previous one, he seeks to save something from the old world, to save something of art, to save appearances, to oppose the old Truths with his own, to transpose the mechanistic analogy of the 19th century into the computational analogy of the end of the 20th century. But let us stay away from such analogies, “*Let us be on our guard against thinking that the world is a living being. Where could it extend itself? What could it nourish itself with? How could it grow and increase? [...] as those do who call the universe an organism? That disgusts me. Let us now be on our guard against believing that the universe is a machine; it is assuredly not constructed with a view to one end; we invest it with far too high an honor with the word “machine”. Let us be on our guard against supposing that anything so methodical as the cyclic motions of our neighboring stars obtains generally and throughout the universe; indeed a glance at the Milky Way induces doubt [...]. Let us be on our guard against saying that there are laws in nature. There are only necessities: there is no one who commands, no one who obeys, no one who transgresses. When you know that there is no design, you know also that there is no chance: for it is only where there is a world of design that the word “chance” has a mean-*

ing [...]. Let us be on our guard against thinking that the world eternally creates the new. There are no eternally enduring substances; matter is just another such error as the God of the Eleatics. But when shall we be at an end with our foresight and precaution? When will all these shadows of God cease to obscure us? When shall we have nature entirely undeified? When shall we be permitted to naturalize ourselves by means of the pure, newly discovered, newly redeemed nature?"³⁴ As for curiosity, this transitory and superficial surprise, only those who do not see the miraculous state of our technologies and this civilization still feel the need, and it is precisely this fantastic relationship between the highest demand of contemporary mathematical knowledge and the banality of technologies which should be at the heart of our research (within the *formal ordinary*). The fantastic relationship " [...] it is fantastic, if you think about it, to have a nose and two eyes, and the nose precisely between the two eyes."³⁵ There are these machines, these machines envisaged by Peano, the future machines of Turing and which will become our computers and "of which we also find a first hint of in Hilbert; he refers to "finite sequences of signs, drawn up according to a finite number of rules (and Hilbert knows what he is talking about since he encodes, in his 1899 book, all the Euclidian and non-Euclidian geometries in arithmetic by an analytical method),"³⁶ and to these machines which are other than human production, we must again and again add something inventive, in order not to stop saying "they are only machines". But, indeed, this "they are only machines" has little chance of existing as a valid philosophical commentary as soon as we begin to perceive what they are. As for the aim of art or architecture, it is, no more today than yesterday, to "embellish life, but to organize it"³⁷ (organization does not require any creativity).

Arithmetization

The "discrete state machines" will therefore repeat certain operations in the strictest rigor and exactitude and as soon as it concerns arithmetic we can envisage it fairly simple. But how can it repeat these operations *for geometry*? By reducing geometry to algebra – which in the last instance will be the Boolean algebra formed by the famous 0.1. Geometry was already a language whose limits were "exploded" with the appearance of non-Euclidian geometries. From now on there will no longer be only one geometry, but a possible infinity leading, for example, to such a list: absolute geometry, affine geometry, algebraic geometry, analytic geometry, birational geometry, complex geometry, combinatorial geometry, computational geometry, conformal geometry, constructive solid geometry, contact geometry, convex geometry, descriptive geometry, differential geometry, digital geometry, discrete geometry, distance geometry, elliptic geometry, Euclidean geometry, finite geometry, geometry of numbers, hyperbolic geometry, information geometry, integral geometry, inverse geometry, non-Euclidean geometry, numerical geometry, parabolic geometry, plane geometry, projective geometry, Riemannian geometry, spherical geometry, symplectic geometry, synthetic geometry, transformation geometry (in this list some geometries encompass others, some are parallel). Of these geometries, we can say certain things. The first is that they are contained in algebra "It would seem that geometry can contain nothing that is not already contained in algebra or analysis, and that geometric facts are nothing but the facts of algebra or analysis expressed in another language"³⁸. The second is that among them several will be able to dialogue within com-

puters, for example in CAGD software. Concerning the first aspect, we have already seen that geometry is an *“intermediary language between that of the analysis and of physics”* and that the choice of such or such a geometry is a convention. But this convention is “argued”, thus for Poincaré not only is geometry in itself a convention, of which one of the main *raison d’être* is the simplification of the world (*“[...] geometry is the study of a set of laws not very different from those whose rules our instruments obey, but much more simple, laws which do not in effect govern any natural object, but which are conceivable for the mind”*³⁹), but the choice of possible geometries is also a question of simplicity. This second simplicity is, however, different. Whilst the first is “philosophical”, this one is “mathematical”, *“That we do not say that the group of Euclid seems the most simple because it conforms to some preexisting ideal which already has a geometric character; it is more simple because some of its displacements are exchangeable, which is not true of the corresponding displacements in the group of Lobatchevsky. In analytical language this means that there are fewer terms in the equations and it is clear that an algebraist who does not know what space is, or the straight line, would consider this as a condition of simplicity.”*⁴⁰ The importance accorded to simplicity reminds us of course of two things. 1) The question of elegance in current programming. 2) The question of optimization of algorithms. The first, which meets partially subjective criteria, is in fact dealt with by Poincaré *“[...] The sentiment of mathematical elegance is nothing but the satisfaction due to some conformity between the solution we wish to discover and the necessities of our mind [...]. This aesthetic satisfaction is consequently connected with the economy of thought.”*⁴¹ The second, which meets strictly scientific criteria, is also dealt with in the sense that an economy of thought allows Poincaré to *“increase the yield of the scientific machine”*⁴² (in contemporary capitalism which is based on science, it is not difficult to state the major role played by the power of calculation and the optimization of algorithms). But what distinguishes Poincaré from a logician here, is that the second form of simplicity does not prevail absolutely over the first, and this is why, in my opinion, the statement by A.I. Miller *“Poincaré’s physics is a reflection on his philosophy”* – a statement taken up by A.F. Schmid – could also apply to the mathematical/philosophical relationship. Indeed, it is difficult to imagine Russel, or even less so Peano, approving, in this era, a definition of mathematical elegance which contained the terms “sentiment”, “satisfaction”, “adaptation” and “mind”. Remember that Peano concluded his reading of a book by mathematician Veronese in 1892 by this cutting assertion, *“We could continue at length enumerating the absurdities that the author has piled up. But these errors, the lack of exactness and rigor throughout the book take all value away from it.”*

Poincaré therefore establishes simplicity as a criterion, the irony being that it is the choice of this very criterion for which he ends up reproaching the logicians. *“[...] It is part of (the analytical definition of the continuum) in the type of these definitions which have become so frequent in mathematics, since we have tended to “arithmetize” this science. These definitions, irreproachable [...] from a mathematical point of view, would not be able to satisfy the philosopher. They replace the object to be defined and the intuitive notion of this object by a construction made with more simple materials; we clearly see that we can in effect create this construction with these materials, but at the same time that we could make many others; what is not evident is the real reason for which we have assembled these materials in this way and not in another.”*⁴³ Therefore,

for the French mathematician there is a search for simplicity which is different from that which Hilbert will search for geometry in his *Fondements de la géométrie*. The problem, despite everything, remains whole, for if Hilbert gives criteria on simplicity (his type of mathematical criterion seems to have its equivalent in contemporary optimization), it is a lot less evident for Poincaré. Indeed, Poincaré is not by any means ready to abandon the language of geometry (abandoning geometry itself would be absurd and would not have the least significance, neither scientific nor philosophical), "*It would seem that geometry can contain nothing that is not already contained in algebra or analysis, and that geometric facts are nothing but the facts of algebra or analysis expressed in another language. It might be supposed, then, that after the review that has just been made, there would be nothing left to say having any special bearing on geometry. But this would imply a failure to recognize the great importance of a well-formed language, or to understand what is added to things themselves by the method of expressing those things.*"⁴⁴ This last argument on the importance of language and of scoring "*in mathematical sciences, a good scoring has the same philosophical importance as a good classification in natural sciences,*"⁴⁵ is perfectly acceptable, but one must admit that we readily understand, as soon as the geometries are reduced to algebra, why the late 19th century logicians thought that there was no reason to become saddled with a language such as geometry, and we, as architects dealing with computers and formal languages, may wonder if it would also be beneficial for us to definitively leave the language of geometry to one side to go towards new types of scoring in architecture. It is of course already effective in many cases, for example with the use of emerging phenomena, but firstly this use does not do without geometry in the framework of architecture, and secondly, it is a question of thinking conceptually about the problem of geometry as a non-necessary language, and not only practically, without which you will end up – as with C. Rowe and his ideal – with nothing much more than Platonic solids – or equivalent appointed elements in the sphere of Free Form Surfaces – implemented under the form of 0.1.

It is thus a question of establishing a clear, conceptual language compared to the different geometric elements which populate current architecture, including of course these Free Form Surfaces. A definition of the criteria, including that of simplicity, in terms which are closer to those of the logicians than those of Poincaré, would also allow one not to systematically associate simplicity with an intuitive and formal simplicity, formal here having the sense of architectural form, or on the contrary to associate the complexity with a mathematical complexity much too evident to become interesting from an architectural point of view. Indeed, as rightly noted by Nicholas Negroponte "*we are all tired of complexity*", but how can we express this without giving arguments to those who are waiting for the least occasion to strengthen the critique of a contemporary architecture straight out of P. Eisenman, F. Gehry or G. Lynn in the name of a humanist, respectable and democratic simplicity? How can we reintroduce some of P. Eisenman's progress made around questions of language and take art from the minimalism of conceptual art to carry out a reversal, since we need to move from the logical reduction which characterizes these movements to a series of formal language games? Perhaps we need a new simplicity, eminently abstract but perfectly defined, which will grasp the *real complexity* of our technologies much better than the current complexity, allowing us to enter into

a more intimate relationship with the very nature of computers and CAGD software, with certain branches of applied mathematics (and the influence for the architecture of P. Bézier, P. De Casteljaou or more recently Chaikin and Catmull), finally with the current states of modeling and simulation.

Simulation

In effect, with this simulation that surrounds us and which we apprehend, we have to operate in a “polyformalized world” where everything is the support (for example climatology) or the consequence (for example the aeronautics industry) of simulations, these simulations which “originated in what we can call an intrinsic polyformalism”⁴⁶ and which create this sort of “ecology of objectivized formalisms”. Now this ecology is simply that which constitutes the merest simulation software, software which tends to replace the most simple modeling software, such as CAGD. Whilst the majority of architects still feel they are operating using a single mathematical model (for example using a single geometry) since they use such a program, which always comforts them more in the acritical use, in reality they are operating using a variety of different models. These models are mathematical and sometimes refer themselves to different axiomatics and to completely different branches or sub-branches: different types of algorithmics, different types of geometries, different paradigms of programming etc. For this reason there should not be a single language for computational architecture, which the buildings/experiments constructed to date tend to show us. Neither is there one single language which could have existed as the “language of modern architecture”. Nor is there a single language which could have existed as the “language of postmodern architecture”, even though this language is found tinkered with and dissolved in a multiplicity of language games. In fact, there is no language to speak of at all. What I mean by that is that computational architecture, taken in the movement that characterizes the rest of contemporary production, is no longer based on any operation established from a standard language, not even a combinatorial operation. Neither is it based on the non-standard variation from a model – which would be a poor understanding of the non-standardization which ought to be defined from the perspective of formal language games – but an absence of language, “*Simulation is not a language for its signs are heterogeneous: that means that simulation uses increasingly different types of mathematical formalisms that it brings together in a non-mathematical way, that is to say, in a way that cannot be reduced to a shared axiomatic. Simulation is neither a discourse nor a language not only because it cannot be resumed but also and principally because it cannot be resumed nor thought because of the heterogeneity of its conceptual tools. The contribution of simulation is not only due to the practical or theoretical limits of the calculability of certain mathematical problems. It is also due to the fact that the information infrastructure allows heterogeneous formalisms to mix, that it to say that cannot be reduced to each other and non-justiciable with the same axiomatic [...]. The simulation gives rise to the history of an ecosystem filled with composite and heterogeneous mathematical beings. It displays a trajectory in the singular dynamic of this ecosystem, without this trajectory being, on first sight, reducible to that of a dynamic system which is correctly formalized and mathematized.*” Now this absence of visibility is the foundation for the majority of critics of contemporary architecture, based on calculation and computers. These very critics would like to see the emergence of a new

axiomatic of architecture, of a “Grand Style” both popular, humanist and absolute. Now what is at least popular and absolute is the massive and radical arrival of computational technologies at the very heart of daily practice. It is the *formal ordinariness*⁴⁷, that is the common and trivial use of formal languages (and their consequences). In any case, if I come back to the problem of geometry it seems impossible to define a valid practice of contemporary architecture using a single geometry or a single formalism. What is before us is a polyformalism, the functioning of which we should understand. What is it in the computer that allows “*diverse mathematical and informational beings to coexist*”⁴⁸?

Simply that which we have seen thanks to the “*discrete-state machines*”; thus “*synchronization by step-by-step processing. At each step of the processing, the formalisms mix and communicate. It is also their own way of becoming homogenized amongst themselves: by successive moments, by sampling. The step thus no longer serves only to process the algorithmic incompressibility – in the case of digital simulation – but also and principally the formal heterogeneity of coexisting objects – in the case of information simulation. Information simulation is not, therefore, a language because the signs are dealt with by various axiomatics, which are sometimes contradictory. It is also the reason for which a simulation cannot be expressed mathematically. As such, it has no grammar, and certainly no generative grammar – even though the simulation can use such grammars from time to time locally, as is the case with L-systems -, it is not a system of signs.*”⁴⁹

Thus, when simulation enters into architecture through the use of different software, it does it no differently than when it enters into the modeling of nature. It is not a geometry which defines this architecture, even though its overall appearance could file it into this or that category (such as “non-Euclidean architecture”) but a multitude of mathematical models associated with a multitude of geometries. Grasping the nature of this architecture and the fundamental difference that it maintains with any other architecture that has preceded it implies grasping the nature of modeling and of “polyformalism”, in fact *formal language games*. Evidently, when I say that we should grasp that which changes radically, I am thinking that this also allows us to grasp that which *does not change*, a possible “invariant” of architecture. Thus it is perhaps a question of re-grasping architecture itself, or at least grasping that which architecture establishes today as a discipline and which does not exist in any other. While many artists, given the broad use of CAGD software, develop in a formal or conceptual manner that which they themselves or the critics define as architecture and which, I believe, only reproduces the poorest sides, such work, initiated by G. Lynn in *Architecture versus Sculpture*⁵⁰ is necessary. As for the complexity mentioned above, which came from emerging processes, it is also typically trans-disciplinary but I do not think at all that it seems to refer to architecture other than by analogies which are too evident, no more than it allows us to realize a completely different complexity, that of polyformalism.

Approximation

Until now we have been concerned with indicating the difference between the mathematical ideality and its absence of correspondence in reality. We have also seen that Poincaré mentions this problem with particular interest, as for him this problem and the obstacles that he includes “*Have not disappeared; they have only been removed to*

the frontier, and will have to be conquered again if we wish to cross the frontier and penetrate into the realms of practice," which implies directing "the main corps of our army,"⁵¹ in the study of reality. This study of reality – and of course the way in which we can act on it in return falls under the sphere of *applied* mathematics. Now, what are the relationships between architecture and mathematics, and more precisely between architecture and geometry if it is not this relation between architecture and applied mathematics? Indeed it would be entirely illusionary to believe that architecture maintains anything other than simple analogous, conceptual and philosophical relationships with pure mathematics. What is then applied mathematics, what can we say about it and what is its development? It seems that for a mathematician like Poincaré applied mathematics is, like pure mathematics, oriented towards a search for relationships. Yet whilst certain mathematicians, including Felix Klein who we will mention below, refer to a fairly broad definition of applied mathematics, it seems that Poincaré bases this question on a limited number of mathematical concepts and tools. Thus, it is not so much a question of applied mathematics in the sense commonly meant today, that is a precise knowledge applicable to this or that branch of research or industry and which has its own development, but rather applied mathematics in the sense of a relationship between mathematics and another discipline, physics. The relationship is finally shifted from pure/applied to non-experimental/experimental and as A. F. Schmid notes, for Poincaré experimental sciences "aim to apply mathematics to the real world."⁵² Thus, and contrary to physics, mathematical science is, for Poincaré and as a whole like geometry "shielded from any revision; no experiment, however precise, can reverse it. If it could, it would have been done long ago."⁵³ Thus, when we are concerned with applied mathematics (we ought only to say "mathematics which does not deal with itself or "non auto-referential" mathematics), it is not so much a question of wondering how to move from the most abstract mathematics to the whole of the concrete realizations that result from it by different approximations (which would appear to be the most logical step from a mathematical point of view), but rather wondering how to enter into the categories of our understanding all of natural phenomena, which is visible in this statement: "Classification is not a raw data of experience [...]. It is thus an active operation of the mind which tries to insert the raw results of experience in a pre-existing form, in a category (My emphasis)."⁵⁴ Thus after having recognized that geometry enjoyed a privileged relationship with the body thanks to the coordinated system (" [...] In sum, the system of coordinated axes to which we naturally (my emphasis) relate all external objects, is a system of axes invariably linked to our body, and which we transport with us"), Poincaré aims to let into our minds the world which surrounds us through the concept of group. Since geometry studies displacements and transformations, and since these movements and transformations can be grouped, then geometry studies the groups. Thus, after having established that there exists "a particular class of phenomena that we call displacements" and that it is "the laws of these phenomena that are the object of geometry," Poincaré jumps to the notion of group: "[...] geometry is nothing other than the study of a group,"⁵⁵ or even "The object of geometry is the study of a particular 'group,'"⁵⁶ The notion of group is, so to speak, at the top of the ladder of conceptual values – and it is perhaps for this reason that Poincaré positions it so high – it seems to have come directly from our minds rather than the work of mathematicians, "[...] the general concept of group pre-exists in our minds, at least potentially. It is imposed on us not as a form of our sensitiveness, but as a form of our understand-

ing.⁵⁷ Further, Poincaré repeats this idea according to which *"in our mind the latent idea of a certain number of groups pre-existed: these are the groups with which Lie's theory is concerned."*⁵⁸ Thus, whatever the limit for all these thoughts which are based on apriorism, for which we wonder why they are so badly shared and why we had to wait so long for them to appear, Poincaré shifts from movement to groups and finally to space. We already knew that space was a sort of convention, we also knew that its Euclidean reading was the most convenient, but we did not know that it could also be a kind of group. Besides, until now Poincaré did not define space in a direct way, as being something of which we could say absolutely what it is. Now the notion of group, Poincaré reminds us that *"that which we call geometry is nothing other than the study of the formal properties of a certain contained group; so that we can say that space is a group."*⁵⁹ Given what the majority of architects implicitly think (implicitly as this is present in the majority of contemporary research, including computational research), saying in sum *"geometry is the science of space, architecture is the discipline which places geometrical concepts before our senses in the most evident manner, therefore architecture is a sort of phenomenological science of space,"* considering like Poincaré that "space is a group", would already be progress. But let us return to the problem of applied mathematics. Poincaré thus emphasizes the concept of group, as we have seen, he also emphasizes differential equations as a tool. If I am coming back to differential equations it is clearly not completely innocent, since under the influence of D'Arcy Thompson (who did not, strictly speaking, use them, but kept the image) they have entered into contemporary architectural discourse through G. Lynn. Now since D'Arcy Thompson, mathematics has gained in complexity, and differential equations are just one tool amongst others. Thus, as F. Varenne reminds us concerning the growth of organisms, a much greater series of mathematical models than with D'Arcy Thompson appears in current simulations, *"Thus the simulation program of the growth of plants AMAP of CIRAD creates graphs – topology – by stochastic processes – laws of probability – in the usual three-dimensional space – geometry. [...] Simulations therefore ensure that several formalisms coexist."*⁶⁰ Now, several formalisms, it is not precisely the way in which Poincaré envisages the description of nature and it even seems that both for him and D'Arcy Thompson or before for R. W. Emerson, *"Each creature is only a modification of the other."* If this is the case, if it is simply a question of establishing the relationship which enables one to move from one phenomenon of nature to another similar one, while differential equations do it very well, *"We can ask ourselves why, in physical sciences, generalization tends to take the mathematical form. The reason is now clear to see; it is not only because we have numerical laws to express: it is because the phenomenon we observe is due to the superposition of a large number of elementary phenomena, all of which resemble each other; thus differential equations are introduced completely naturally."* Equations thus seem to be the mathematician's ideal tool since his ideal science has to adapt to the particularities of nature, and we must note here that when computer use first became widespread in different branches of applied sciences, in the 1960s and 1970s, numerical calculation and differential equations had not yet lost their privileged status. In any case, for Poincaré *"mathematics teaches us [...] to combine same with same,"*⁶¹ and *"allows us to know real, profound analogies, those which the eyes do not see and that reason can only guess at."*⁶² When it is a question of establishing the report which goes from one species of fish to another, D'Arcy Thompson establishes a series of grid transformations, and the relationship between the first network of lines

and the second which is perpendicular to it is a usage taken from differential equations. In addition, what we see with D'Arcy Thompson is – and with other points (though not all) – completely in accordance with what Poincaré said about this “*mathematical mind which disdains the matter in order to only become attached to the pure form. It is he who taught us to name with the same word beings which differ only in their matter.*”⁶³ We have seen that Poincaré sees the differential equation as the privileged tool of all studies on “physical” similarities” but in reality he goes further, he exceeds the simple study of similarities, and the approximation of the physical phenomena that we might have seen in this initiative, he establishes, when he comes back to Newton’s mechanics, the differential equation as a manifestation of the law “[...] *it is needless to recall that Newton it was who enunciated the oldest, the most precise, the most simple, the most general of all natural laws.*” “*One law for us [...], it is in constant relation between the phenomenon of today and that of tomorrow; in a word, it is a differential equation.*”⁶⁴ It would not be from H. Poincaré that we would find out any more on this major phenomenon, that is the generalized application of mathematics, the mathematization of the real, a real which is not designed as a noble and unattainable object which constitutes the *raison d’être* of nature sciences, but a trivial, daily real, which constitutes our machines and which allows the production of further machines, which incarnates the everyday activity of the engineer or the industrial researcher at work. Therefore there is little in Poincaré, who is so preoccupied with the philosophy of science, there is more however, with his contemporary F. Klein, who envisages applied mathematics from a less abstract angle. Thus, discussing the contributions of S. Lie in a conference given in Chicago on 30 August 1893, F. Klein lists two examples of an application of this new knowledge linked to S. Lie, which focuses on “*contact transformations*”. We encounter the first “*in Astronomy in the theory of perturbations,*” the second concerns the entirely practical problem “*relative to the problem of chains in cog-wheels. The profile of the cog of a wheel being given, how do we find the profile of the other.*” Klein also states that he has already brought this problem up in Chicago, “*explaining using models sent to the Exhibition by German universities.*”⁶⁵ This last example allows us to learn a lot about the daily use of mathematical knowledge within contemporary scientific societies. In addition, not only does F. Klein show the transition from the highly abstract field of mathematics to an apparently trivial question of engineering, but in this kind of report he sees the main issue as being the knowledge to come. For F. Klein it is a question of concrete thought on the way in which pure mathematics can be transmitted to practice, whilst amongst the students, “*The majority of them only study mathematics with a view to practical applications.*”⁶⁶ What F. Klein wants to avoid is “*the danger of a split between abstract mathematical science and its scientific and technical applications. Such a split would be deplorable; the result would be to base applied sciences on an uncertain foundation and to isolate the scientists who deal only with pure mathematics.*”⁶⁷ F. Klein wonders whether it is possible, to facilitate the practical use of pure mathematics without a loss in rigor “*to create a, let us say, abridged system of mathematics, adapted to the needs of the applied sciences, without passing through the whole realm of abstract mathematics.*”⁶⁸ F. Klein’s intuition is remarkable in all respects. One needs only to skim through contemporary literature dedicated to applied mathematics to see to what point a multitude of these abridged systems has appeared, but another remark of F. Klein also attracts our attention. It is the importance he attaches to the notion of interpolation, “*such a system (the abridged system) should*

contain, for example, research by Gauss on the exactness of astronomical calculations or more recent research of such great interest, relative to interpolation, that we owe it to Tchebycheff.”⁶⁹ Thus, whilst Poincaré highlights a single tool, the differential equation, F. Klein highlights that which appears more like a notion, something which is still in gestation and which will be of the highest importance for all applied mathematics, and precisely for that which concerns us architects. Thus, the interpolation from polynomials will undergo important developments in the 20th century, often from “applied mathematicians” or engineers. P. Bézier, who will use the works of Russian mathematician Bernstein, is an engineer with Renault. P. de Casteljou is also an engineer with Citroën, S. Coons is a consultant with Ford, J. Ferguson with Boeing and W. Gordon works for General Motors. Compared to the history of mathematics seen from the perspective of a history of great discovery, founding theorems and major figures (e.g. the analogical “method” of S. Giedion in *Space, Time and Architecture*), there is this more local history, that which has its origins in the very practice of applied mathematics, that which is developed in order to surpass a temporary difficulty in a certain branch of industry and which finally exceeds it until it brings about a flood of new applications. This history has had the greatest influence in postwar industry, it is also that which has had a significant influence on contemporary architecture and which makes it what it is today. Whilst for S. Giedion (or B. Zevi) there could only exist analogies coming from the most abstract physics to be passed into a practice of architecture that is in the end traditionalist, for a contemporary theorist there is an infinity of local practices for which the hierarchy between a conceptual approach and a down-to-earth practice does not exist. The use of such a polynomial curve rather than another has a practical importance (*“An important question of performance has been resolved: the Bezier form is more stable in digital terms than the Monomial form. Farouki and Rajan observed that the digital inaccuracies which are inevitable when using computers of finite precision, affect the curves in the Monomial form in a considerably greater manner than those in the Bézier form,”*⁶⁰) but it also has a conceptual significance, which does not appear with what I have mentioned until now. The simple question of digital exactness and stability of such or such a model therefore has an architectural importance in itself which it would be possible to relate to the interest shown by an architect such as Mies van der Rohe in details, but with a consistent shift in that which we mean by the term *detail*.

Exactness

Contemporary architecture has certainly learnt – if not taken – a certain number of forms and concepts from F. Klein. Rather than coming back to these questions of form – although it is clear that the form remains an architectural problem in its own right but which I associate with a series of conceptual and practical problems and not to *space* -, I have brought up certain aspects of Klein expressing an opinion on the status of applied mathematics. There is a final aspect that concerns the question of exactness. This, like stability, is at the heart of the problems currently encountered in the industry, as seen in this example: *“If we decide to use the Bézier form for reasons of stability, while it is essential that no conversion is made in other representations, this would destroy the precision gained by using the Bézier form.”*⁷¹ Thus, through the very example of exactness, F. Klein gives us a clear idea of that which could be the relationships between pure mathematics/applied mathematics, and in this way he not only gives us

an idea of what architecture could maintain as a relation other than analogical with pure mathematics or with geometry, but he informs us generally about the status of all disciplines thanks to a new type of criterion, which has the advantage of being perfectly cross-disciplinary. Thus, Klein states, *"I believe that the more or less close relation of any applied science to mathematics might be characterized by the degree of exactness attained, or attainable, in its numerical results. Indeed, a rough classification of these sciences could be based simply on the number of significant figures averaged in each."*⁷² Klein's proposition is not only radical, it is visionary. Radical, as it implicitly implies that a science that reaches such a degree of exactness would be merged with mathematics to the point that it becomes impossible to establish a difference other than a "cultural" or a "social" one. It would thus be entirely possible, in the not too distant future, that the mathematical difficulty and rigor of the problems encountered in applied science are so great, that he who resolves them will not be perceived as a "pure" scientist. The qualifier "pure" will therefore no longer have a merely social character, as for the doctor thus named, particularly as it corresponds to the image that we have, even though an infinity of other persons who work in laboratories would have an identical knowledge, or even a greater knowledge. This convergence does seem an inescapable *fact*, it corresponds to the transfer from a technical civilization which is based on the engineer and on knowledge as a means of technological civilization which is based on the figure of the researcher and on knowledge as an end. It is not difficult to distinguish those who still feel a certain nostalgia for the first solution, claiming that we match the ends and the means (without even considering the value of the ends in question) and those who, like Hilbert, do not hesitate in stating: *"We must know. We shall know."*⁷³ However, it is not only the mathematicians who hold such a discourse, R. Musil affirms in HSQ more or less the same thing, *"The scientist, today, is unavoidable: we cannot refuse to know!"* But, returning to F. Klein and his proposition to classify sciences according to their exactness, does he give examples? Yes, *"But astronomy (and some branches of physics) would here take the first rank; the number of significant figures attained may here be placed as high as seven, and functions higher than the elementary transcendental functions can be used to advantage. Chemistry would probably be found at the other end of the scale since in this science rarely more than two or three significant figures can be relied upon. Geometrical drawing, with perhaps three to four figures would rank between these extremes; and so we might go on."*⁷⁴ Of course, it is a question of listing sciences in the state in which they were at the time, that is around 1890, because the exactness reached today in chemistry, where it is possible, using nanotechnology, to manipulate an electron itself, is without comparison. Indeed the technology available at the time does not always immediately follow the appearance of the theory on which it is based. Thus, a certain period of time was needed for the first computers to be used outside the operational research laboratories used by the military, hence this feeling, shared by the population, that a good part of science "is useless". In effect, this is true at the time. In addition, F. Klein specifies that, *"It must not be forgotten that mathematical developments transcending the limit of exactness of the science are of no practical value [...], the amount of mathematics that can be usefully employed in any science being in proportion to the degree of accuracy attained in the science." This is why there are "extensive mathematical theories that do not exist for applied science [...] the investigations on the convergence of Fourier's series, the theory of non-analytical functions etc."* If we observe Fourier's series, we know that today they are widely used in signal

processing. What is extraordinary in reality, is that one single tool, the computer, both invalidates the outline of the classification of science as created by F. Klein, but at the same time it strengthens its principal intuition on the importance of the concept of exactness. What the computer carries out, so to speak, is a general “flattening” of all of applied sciences. It will give every one the possibility to acquire new “exactness”, so that in chemistry we can operate on the scale of the nanometer, but also in biology and in a whole host of other fields. The computer will allow mathematical exactness to be applied to everything it touches, that is to say to everything around us. Thus, current technologies will go further to strengthen this intuition of F. Klein, and John Von Neumann, a mathematician as important in the 20th century as F. Klein in the 19th century, also emphasizes the concept of exactness. In a conference given on 20 September 1948 in Pasadena, called “The general and logical theory of automata,” Von Neumann states: *“The important difference between the noise level of a digital machine, as described above, and of an analogy machine is not qualitative at all; it is quantitative. As pointed out above, the relative noise level of an analogy machine is never lower than 1 in 103, and in many cases as high as 1 in 102. In the 10-place decimal digital machine referred to above the relative noise level (due to round-off) is 1 part in 102. Thus the real importance of the digital procedure lies in its ability to reduce the computational noise level to an extent which is completely unobtainable by any other (analogy) procedure. [...] This is clearly an entirely different milieu, from the point of view of the reduction of ‘random noise’ from that of physical processes. It is here – and not in its practically ineffective absolute reliability – that the importance of the digital procedure lies.”*⁷⁵

Now, if applied sciences are tending to become more and more rigorous, it is owing to the new importance (as they are *practically* applicable) given to the concept of exactness thanks to the computer. It seems that no discipline has escaped this deep change, including architecture. The latter is evidently by no means an applied science, but as soon as it becomes involved, as is the case today, with such a great number of technologies, it enters into a relationship with applied science. Thus, the qualitative gain (that of details in the strict sense of the term) of all contemporary constructions is directly linked to the gain of exactness allowed by digital technologies. The automatic and mechanical character of this relationship of cause and effect explains why those who have incorporated (since P. Eisenman) the conceptual status of architecture are forever seeking different criteria, and are not content with “the same but better”. We have seen that the difference between an analogical and a digital machine is, despite everything, quantitative, but the difference between the civilization which proceeds the arrival of the computer and that which we know today is qualitative, and the same is true for architecture. Thus, and here will I end, when P. Bézier creates his digital methods for defining curves and surfaces, he has this quantitative difference in mind. What he is looking for is not so much to produce new forms for elements of the car body, but their rigorous definitions, with the principal aim of simplifying fabrication and optimizing costs. Here is how Pierre Bézier spoke about his work at the equipment research department at Renault: *“The department had to choose, design and implement the production facilities of mechanical components. All the surfaces which required a certain precision were planes, cylinders or cones, i.e. to define them we only needed straight lines and circles. [...] The limits were in thousandths of mms since the tolerance was a matter of hundredths, and even less sometimes. Generally, arguments with controllers were over one or two thousandths and then the measurement instrument, known as*

screw gauge or comparator, was referred to as “the magistrate” in the workshop jargon. As for the car body, it was the opposite: vagueness prevailed. The stylist was the referee: his judgment could only be subjective and sometimes would vary with time. There was no requirement for mathematical knowledge for anybody. [...] The drawings were not particularly accurate, and for example, once [...] a car ended up with its two sides differing by several millimeters. [...] In terms of aesthetics and aerodynamics, it did not matter. But during the manufacturing, it turned out to be problematic: sometimes there were several millimeter voids between parts which should have fitted edge to edge together, and these voids had to be filled in with tin welding, which was expensive. [...] I felt that an unquestionable definition, which would remain the same and would be easy to pass on, was a necessary step to take; the definition should be fixed by the industrial designer himself and then passed on as numerical data to every department, including subcontractors and suppliers involved in the process, ranging from the industrial designer to the controller, operating at the end of the manufacturing line, and also to the maintenance shops of the network of agents and main dealers.”⁷⁶

This essay, written from January to March 2005, was formerly dedicated to the proceedings of the Symposium LOOPHOLES between Discourse & Practice, Harvard Graduate School of Design, April 15th & 16th, 2005. It has been published with a series of other essays dedicated to the epistemology of computational architecture, in *Five Essays on Computational Design, Mathematics and Production*, Haecceity Papers (Daniel Pavlovits Ed.), Volume 3/issue 2, Spring 2008, ISSN 1832-8229.

Notes

- 1 R. W. Emerson, *La Nature* (Nature), 1836, p. 34.
- 2 H. Poincaré, *La science et l'hypothèse* (Science and Hypothesis), chap. *L'espace et la géométrie* (Space and Geometry), Flammarion, Paris, 1902, p. 87. The majority of the quotes from H. Poincaré come from the work *Henri Poincaré, Les sciences et la philosophie*, Anne-Françoise Schmid, ed. L'Harmattan, Paris, 2001.
We will refer to this work for an overall understanding of the philosophy of Henri Poincaré's sciences, as well as to the correspondence between L. Couturat and B. Russell which throws light on Poincaré's positions. *Bertrand Russell, correspondance sur la philosophie, la logique et la politique avec Louis Couturat (1897-1913)*, ed. Kimé. Ed. and commentary A.-F. Schmid.
- 3 F. Klein, Conference given to the Mathematics Congress on the occasion of the Chicago Exhibition.
Conférence IV Sur la véritable forme des courbes et des surfaces algébriques (On the real form of curves and algebraic surfaces), 31 août 1893.
- 4 H. Poincaré, *La science et l'hypothèse* (Science and Hypothesis), chap. *L'espace et la géométrie* (Space and Geometry), p. 89.
- 5 I borrow this term from Franck Varenne and link it to my own hypotheses on “formal language games” defined as computational and formal linguistic constructions. Cf. *Infra* for the works of F. Varenne.
- 6 G. Lynn, *Ineffective DESCRIPTIONS: SUPPLEMENTAL LINES*, in: RE: WORKING EISENMAN. Academy Editions, 1993.
- 7 H. Poincaré, *op. cit.* chap. *L'espace et la géométrie* (Space and Geometry).
- 8 H. Poincaré, *op. cit.* chap. *L'espace et la géométrie* (Space and Geometry).

- 9 H. Poincaré, *op. cit.* chap. *Les géométries non euclidiennes* (Non-Euclidean Geometry).
- 10 H. Poincaré, *La Valeur de la science* (The Value of Science), Flammarion, Paris, 1905.
- 11 *Ibid.*
- 12 H. Poincaré, *op. cit.* chap. *L'espace et la géométrie* (Space and Geometry).
- 13 H. Poincaré, *La science et l'hypothèse* (Science and Hypothesis), *op. cit.*
- 14 M. Planck, *Positivism and the physical image of the world*, 1931. Conference given to the Kaiser-Wilhelm-Gesellschaft.
- 15 M. Planck, *Significance and limits of science*, 1947. Conference given to the Harnack-Haus de Berlin-Dahlem.
- 16 H. Poincaré, *La Valeur de la science* (The Value of Science), *op. cit.*
- 17 F. Nietzsche, *Le Gai Savoir* (The Gay Science), 1882, § 112.
- 18 H. Poincaré, *op. cit.*
- 19 H. Poincaré, *Science et Méthode*, (Science and Method) Flammarion, Paris, 1908.
- 20 H. Poincaré, *Dernières pensées*, Flammarion, Paris, 1913.
- 21 *Ibid.*
- 22 H. Poincaré, *Science et Méthode* (Science and Method), Flammarion, Paris, 1908.
- 23 A famous example for this new figure, the engineer/researcher who is gradually replacing the engineer/specialist worker can be found in the CERN in Simon van den Meer, a Dutch engineer who invented the method of stochastic cooling used during experiments UA1 and UA2 which allowed the "observation" of particles W and Z. cf. A.-F. Schmid, *L'Age de l'Epistémologie, science, ingénierie, éthique* (The Age of Epistemology, science, engineering, ethics), ed. Kimé, Paris, 1998. Elsewhere, in industry it is clear that this figure plays a considerable role, one only needs to observe the R&D department of DuPont and its concept of "integrated science" hence the following commentary by A. Reverchon (*Spécial ingénieurs*, Le Monde, 24/04/01): "The use of new technologies in communication has, however, boosted another concept, which has challenged the predominance of the market: innovation [...] Alongside the manager engineer emerges the figure of the industrial researcher, an expert in his field. Again companies, as well as schools, need to recognize the strategic importance of it and consequently develop it.
- You could ask me why I am using the figure of the research to discuss geometry in architecture. Firstly, this figure of engineer/researcher was incarnated by both Pierre Bézier and Paul de Casteljaou, whose indirect influence on the whole of contemporary architecture cannot be underestimated. Secondly, it seems that it is unnecessary to produce a critique of contemporary architecture without including a critique of the figure of architect (which architects as varied as Le Corbusier, L. Hilberseimer, H. Meyer ou Buckminster Fuller have done).
- 24 Amy Landesberg, quoted by G. Lynn, *New Variations on the Rowe Complex*, ANY 7/8, 1994.
- 25 H. Poincaré, *La Valeur de la science* (The Value of Science), *op. cit.*
- 26 A.-F. Schmid, *Henri Poincaré. Les sciences et la philosophie* (Science and Philosophy), L'Harmattan, Paris, 2001.
- 27 H. Poincaré, *La science et l'hypothèse* (Science and Hypothesis), *op. cit.*
- 28 H. Poincaré, *La science et l'hypothèse* (Science and Hypothesis), chap. *Sur la nature du raisonnement mathématique* (On the Nature of Mathematical Reasoning).
- 29 H. Poincaré, *Les mathématiques et la logique*, *Revue de métaphysique et de morale*, n° 14, 1906.
- 30 A. Turing, *Computing Machinery and Intelligence*.
- 31 F. Nietzsche, *Le Gai Savoir* (The Gay Science), 1882, § 112.
- 32 H. Poincaré, *La Valeur de la science* (The Value of Science), *op. cit.*
- 33 J. Paulhan, *Braque le patron*, Editions Gallimard, Paris, 1952.

- 34 F. Nietzsche, *Le Gai Savoir* (The Gay Science), 1882, § 109.
- 35 J. Paulhan, *Braque le patron*, Editions Gallimard, Paris, 1952.
- 36 Giuseppe Longo, Laplace, *Turing et la géométrie impossible du «jeu de l'imitation» : aléas, déterminisme et programmes dans le test de Turing.*, Conférence au colloque Cognition, meaning and complexity, Univ. Roma II, Juin 2002.
- 37 El Lissitzky, *The Blockade of Russia Moves Toward Its End*, in Veshch, 1922. Quoted by M. Hays, *Modernism and the posthumanist subject: the architecture of Hannes Meyer and Ludwig Hilberseimer*, MIT Press, 1992.
- 38 H. Poincaré, *Science et Méthode* (Science and Method), Flammarion, Paris, 1908.
- 39 H. Poincaré, *Dernières pensées*, op. cit.
- 40 H. Poincaré, *Des fondements de la géométrie*, The Monist, janvier 1898.
- 41 H. Poincaré, *Science et Méthode* (Science and Method), Flammarion, Paris, 1908.
- 42 H. Poincaré, *La science et l'hypothèse* (Science and Hypothesis).
- 43 H. Poincaré, *Dernières pensées*, op. cit.
- 44 H. Poincaré, *Science et Méthode* (Science and Method), Flammarion, Paris, 1908.
- 45 H. Poincaré, *Savants et Ecrivains*.
- 46 F. Varenne, *La simulation comme expérience concrète*, in. Le statu épistémologique de la simulation, actes des 10èmes journées de Rochebrune (février 2003), Rencontres interdisciplinaires sur les systèmes complexes naturels et artificielles. Avec le soutien de l'European Conference on Artificial Life (ECAL).
- 47 Cf. Philippe Morel, *Why research and contemporary architecture should be different: observations on a recent development and on one or two concepts, including integral capitalism, naturalization and formal ordinariness*, in. Archilab2004, Editions HYX, Orléans, 2004.
- 48 F. Varenne, *Ibid.*
- 49 F. Varenne, *Ibid.*
- 50 in. Peter Eisenman. *Barefoot on White-Hot Walls*, MAK, Hatje Cantz, 2005.
- 51 H. Poincaré, *Science et Méthode* (Science and Method), Flammarion, Paris, 1908.
- 52 A. F. Schmid, *Ibid.*
- 53 H. Poincaré, *Des fondements de la géométrie*, op. cit.
- 54 H. Poincaré, *Des fondements de la géométrie*, op. cit.
- 55 H. Poincaré, *Sur les hypothèses fondamentales de la géométrie*.
- 56 H. Poincaré, *La Science et l'Hypothèse* (Science and Hypothesis), op. cit.
- 57 *Ibid.*
- 58 *Ibid.*
- 59 H. Poincaré, *Des fondements de la géométrie*, op. cit.
- 60 F. Varenne, *Ibid.*
- 61 H. Poincaré, *La Science et l'Hypothèse* (Science and Hypothesis), op. cit.
- 62 H. Poincaré, *La Valeur de la science* (The Value of Science), Flammarion, Paris, 1905.
- 63 *Ibid.*
- 64 H. Poincaré, *La Valeur de la science* (The Value of Science).
- 65 F. Klein, Conference given to the Mathematics Congress on the occasion of the Chicago Exhibition. *Conférence III, Sophus Lie*, 30 August 1893.
- 66 F. Klein, Conference given to the Mathematics Congress on the occasion of the Chicago Exhibition. *Conférence VI, Sur le caractère mathématique de l'intuition de l'espace et sur les relations des*

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67 *Ibid.*

68 *Ibid.*

69 *Ibid.*

70 G. Farin, *Courbes et surfaces pour la CGAO*, Masson, Paris, 1992. Original, *Curves and Surfaces for Computer Aided Geometric Design*, Academic Press, Inc. 1990.

71 *Ibid.*

72 F. Klein, Conference given to the Mathematics Congress on the occasion of the Chicago Exhibition. *Conférence VI*, op. cit.

73 Epitaph on David Hilbert's tomb. On the scientification of the world we can at least see that during the Congress of Mathematicians on 8 August 1900 when Hilbert set out his 23 unsolved problems, the number of participants was around 220. In 1990 at Kyoto there were 6000.

74 F. Klein, *Ibid.*

75 John Von Neumann, *The General and Logical Theory of Automata*, in *Collected Works, vol. V: Design of Computers. Theory of Automata and Numerical Analysis*, p. 295, A-H. Taub ed., Pergamon Press, Oxford, 1963. Quoted by Dominique Pignon in *L'ordinateur et le cerveau*, ed. Champs Flammarion, 1996.

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**Towards a New Kind of Building,
a Designer's Guide
to Newstandard Architecture**

As the world turns

The world is changing. So is architecture, the art of building. Since the world is evolving its communication and manufacturing methods drastically and with increasing speed, architecture will never be the same. It comes down to the provocative assumption that in the end all building components must be designed to be active actors. Based on 20 years of practice of newstandard architecture I have come to the conclusion that buildings and their constituting components no longer can be seen as passive objects. This assumption revolutionizes the way the design process is organized, the way the manufacturing process is organized, and the way we interact with the built structures. The new kind of building is based on the invasion of digital technologies into the building industry and into the design process, such as parametric design, generative components, file to factory production process of mass customization, embedded intelligent agents. I investigate the effects the paradigm shift from mass production to mass customization may have for the designers mind. When the designer is open for this new reality, architecture will never be the same. I will give here one example to visualize the consequences of a truly mass production esthetic. The Cockpit in the Acoustic Barrier project that was finished end of 2005 features 40.000 different pieces of steel, and 10.000 different pieces of glass. Not a single building component is the same in this structure. The radicality of this mass-customized specimen of newstandard architecture equals that of the 50+ year old Mies van der Rohe's Seagram building, which is the ultimate esthetic expression of mass produced architecture. Mind you, the Seagram building is beautiful, but I would never fancy to strive for such esthetic again, now it is time to find the proper architectural expression for the actuality of industrial mass customization. I predict that within 50 years customization in any form – not necessarily in the form of double curved geometry - will be the dominant language of [inter]national architects.

The informed point cloud

As the world keeps turning we will need to redefine the foundations of architecture from time to time. Now more then 20 years have passed since the introduction of the PC, since the emergence of the global Internet, since embedding miniaturized information technology in our consumer products. Today we have become familiar with remote control, wireless internet, with intelligent agents active on the internet, with intelligent agents embedded in consumer products like printers, cars and computers, but we have not seen much change in the very building blocks of the built environment, as of yet. Neither have we seen much change in the way we design and build our environment. We have indeed developed computer programs to simulate otherwise traditional building materials like concrete, steel, glass, composites in a Building Information Model [BIM]. Often the BIM is used to improve known designs, largely because most designers do not take advantage of the BIM to develop new design methods, with the aim to realize designs that are not possible with the traditional design techniques. In a BIM the simulated building components are tagged, the tags containing information on their qualitative and quantitative properties. It sure is an opportunity missed that most architects do not use digital design tools in the early design process. Even on respected universities the students are often told not to use the computer to design. It is my explicit opinion that students in architectural facul-



Fig. 1

Mass production esthetic, Seagram Building, New York, architect Mies van der Rohe 1958.

ties should play in the very design process with all kinds of new digital and social media, as from day one. Sketching in itself is fine, but do express yourself on your touch-screen tablet, use your smart phone to interact and participate - as I conducted some experiments with interactive lectures at Hyperbody - translate your design concept immediately into a [Grasshopper] script, such that you can play with the parameters and open up your design process to others. The actual emphasis on the “drawing” as advocated at the TU Delft by Michiel Riedijk is conspicuously counterproductive in this



Fig. 2

Mass customization esthetic features 1000 unique windows, Al Nasser Headquarters, Abu Dhabi, architect ONL [Oosterhuis_Lénárd] 2012.

respect. In my view the drawing and the section are nothing more than a “flattened” derivative from the 3d model. The drawing and the section should never be the starting point for any spatial design. Building 3d models must belong to the core skills that students in our era are taught. The 3d model contains all information, while the draw-

ings and the section only allow for a poor restricted view of the spatial conditions. Using new media makes the design process transparent, verifiable and participatory, and allows for a stronger individual expression at the same time. New media will not replace the old media of language, thinking, conceptualizing, and sketching, but what new media do is to facilitate you to work inside evolution, such that you will participate as an active player in our evolving society. With this writing I want to show a possible way forward, forward to the basics of the profession of architecture.

To take that step forwards I imagine the built structure to be represented by a point cloud of floating reference points, reference points that move all the time like the birds in the swarm. The points of the point cloud are continuously informed to behave. The points receive streaming information, the points process the streaming information, the points produce new streaming information. Indeed like the birds in the swarm. Complexity based on simple rules. The crux of the new kind of building is that all reference points will be informed in a streaming fashion both during the design process and during its subsequent life-cycle. Even if we are commissioned to design for a static environment, we must set up the BIM in such a way that all constituting components potentially can receive, process and send streaming information. The BIM will understand its deeper meaning as Building In Motion. Imagine a sound barrier that unfolds only when there is an actual noise source. No noise, no barrier. The noise informs the barrier to unfold and to form a sound insulating shell around the noise source, for example around a train that passes through the city. A wave of the unfolding shell travels along with the speed of the passing train. When there is no train, and that counts for most of the time, there is no need for a barrier. Everyone despises the ugly fences along our highways and along our train tracks. The strong logic of facilitating streaming data to inform built structures makes me confident that this concept of Building In Motion is completely realistic and will become a dominant framework for buildings within 50 - 100 years. Let's be prepared for this future, let us make designs as to feel its ultimate logic and seductive beauty. It is the beauty of complexity based on simple rules. Think of pieces of steel, concrete, glass, composites with embedded RFID tags to begin with, with microcomputers later, and with a variety of actuators to come. With the Hyperbody group and various groups of students at the TU Delft I have designed and built several prototypes during the last decade showing the enormous potential for a dynamic architecture. With the Barrier In Motion concept we have identified a functional application for the theory of informed point clouds, promising to become the basic building blocks for a streaming connectivity between all constituting building components. Informed building blocks become the actors in an ecology of interacting complex adaptive systems, in the Internet of people and things.

Forward to Basics

The underlying message of this essay could very well be: Forward to Basics. The implicit assumption is that the basic building blocks of architecture need to be redefined. It is not bricks and mortar, neither is it bits and bytes exclusively. It is rather the merge of bits and atoms which we are concerned about. It is the merge of the old organic real and the new real, the virtual real. One merges into the other, and vice versa. The new buildings blocks are informed components, hardware augmented with



Fig. 3

Parametric CNC produced building blocks, Hyperbody 2010.

software, mapped on each individual building block. Each individual building block will communicate in a streaming fashion via embedded tags [RFID] with other buildings blocks, anywhere, anytime, anyhow, anyway. Thus driving our profession into the vibrant era of synthetic architecture. Synthesizing architecture means redefining the very building blocks and building up a new language from scratch. Synthetic architecture has since been subject to a sequence of evolutionary steps: from liquid architecture [Marcos Novak 1991] via transarchitecture [Marcos Novak 1995] and Programmable Architecture [Kas Oosterhuis 1999] to the notion of newstandard architecture [Frédéric Migayrou / Zeynep Mennan 2003]. Nowadays it is known practice among advanced students and young digitally educated professionals to use Generative Components [Robert Aish / Bentley Systems], Grasshopper [Rhino plugin], Digital Project [Gehry Technologies], Processing, or similar parametric scripting software to synthesize the new language of architecture. ONL's pro-active contribution in this field has been to actually built on a larger scale newstandard benchmark projects as early as 1997 [Waterpavilion], 2002 [WEB of North-Holland] and 2005 [Cockpit in Acoustic Barrier]. ONL has effectively built the connection between the bits and the atoms as to prove that the direction taken on as early as beginning of the nineties was the right choice. The forward looking approach has lead to the new kind of building, based on thoroughly redefined genes of architecture. Forward to basics.

Forward since we do not want to look back. Now in the deep economic depression is the perfect time for innovation in the architecture and construction business, it is the

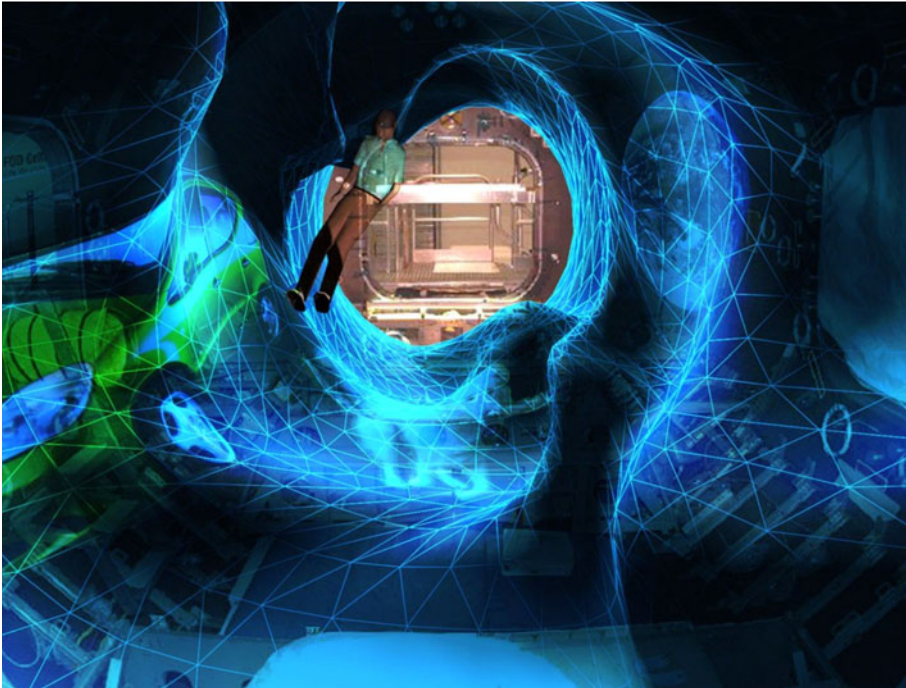


Fig. 4

Programmable interior for Space Station, architect ONL [Oosterhuis_Lénárd] 2000.

proper time to rethink the basis of our society, thanks to the internet bubble and the mortgage crisis. It is the proper time to implement streaming newstandard made to measure [maatwerk] strategies in all businesses related to the building industry, from designers to manufacturers. Forward to basics does not mean to step back to what we knew already 20 years ago, that would be back to basics. Forward to basics means redefining our core business, redefining architecture, redefining the building industry, redefining the behavior of built structures, redefining the interface of buildings. Redefining the very essence of our profession.

Unique address for each building component

The very essence for the designer software I am interested in is to see all constructs [buildings, installations, environments] as in principle dynamic structures, consisting of a large set of thousands of programmable components. Programmable components are individuals with a unique identity, they have a unique address, in the same fashion as all computers are assigned unique IP [Internet Protocol] addresses. Only because of this unique IP address each individual computer can be connected - as an actor and as a receiver - to the global Internet. When a building component has an address, it can receive instructions, it can accept information either pulled or being pushed from a database. Receiving processing and sending data means that this building component becomes an actor, that it can change its configuration. This has been the basis for the pure invention that is the ONL project Trans-Ports imagined in

1999, and in ONL's proposal for the programmable interior of the International Space Station. The invention is to regard buildings as instrumental bodies, which can change their shape and content in real time. To be more specific, a programmable building component could be an actuator in the form of a hydraulic cylinder with embedded sensors, a structural member which has the capacity to adjust its length by becoming longer or shorter, by adjusting their stroke. In the theoretical yet realizable Trans-Ports project it is calculated that only a limited number of approximately $5 \times 6 = 30$ programmable large actuators is needed as to evoke the behavior of the dynamic body. The skin of the body would have to be flexible, which is realized by introducing a folded 3d skin loosely fixed to the dynamic structure with the capacity to stretch and shrink. In the example of the Trans-Ports multi-modal pavilion the skin loosely follows the structure. From the moment one starts to think of a building body as a dynamic construct, a wealth of new possibilities appear at the designers horizon, seducing the designers to become pioneers once again. Not modernist, but truly modern and above all actual.

The need for non-linear software

For the design of complex and programmable buildings a basic condition is to work with parametric software. The concept of parametric design is in itself nothing new, it exists for more then 30 years, originated in the shipbuilding industry. Looking more closely into the achievements of the shipbuilding industry, where the design and build task usually is to build large scale one-offs, is useful for understanding the direction where architecture will be heading for in the coming decades. Customization will be the buzz-word, architects will base their designs on a variety of series of mass customized one-offs rather than relying on the outdated serial approach of mass produced components. This can only be achieved when we build our 3d models in a comprehensive *parametric* way. Parametric design basically means building bidirectional relations, relationships between each individual building component, no exceptions allowed, not "dead" isolated objects. Literally every seemingly soft design decision must be modeled as a hard parametric fact, verifiable by numbers. Now suppose the designer switches to another design rule, suppose the designer changes the rules while playing the design game. That means that the parametric model will need to be restructured from the beginning, which is an even more drastic feedback loop in the evolution of the design. To work with changing rules during the design process we need new species of software, which must be less hierarchical, less linear, and more intuitive, more *immediate* instead. The relations between the components will need to be more flexible, more like the members of a dynamic swarm indeed.

Feel the force

A parametric relationship must be understood in terms of information exchange. Consider this sentence: "I place a cup on the table". The I informs the cup to be placed on the table. Then replace the "I" with the designer, the cup with component 1 and the table with component 2. The designer informs the bottom surface of component 1 to be connected to the top surface of component 2. To be able to design software for

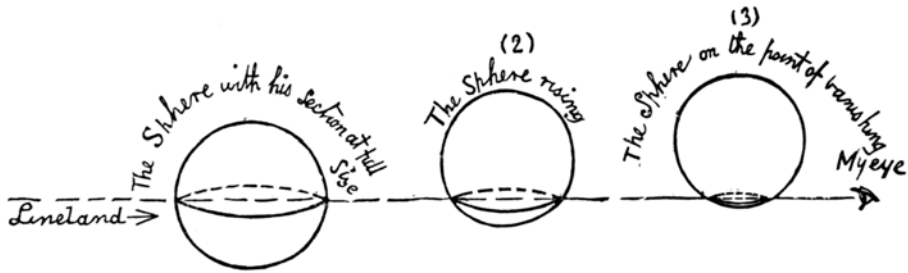


Fig. 5

Flatland, A Romance of Many Dimenions, author Edwin Abbott Abbott 1884.



Fig. 6

Swarm behavior forms the basis for protoBIM and quantumBIM.

parametric structures it is crucial to make a complete functional description – a script, a scenario if you wish – of all relations between component 1 and component 2. The two components need to share a point of reference, separately specified for both components. The points of reference are the active members of the point cloud. Once the points have been defined properly, one may connect the two points, as to share the same coordinates in an agreed coordinate system. Once connected the two components must calculate the area of contact they share. If the bottom part of components is flat it will be the full surface area of the standing part which is shared. This area will be used for the structural calculations transferring the loads from standing to lying element. I Ultimately it is my intention to be *empathic* to the force fields be-

tween the components, as to feel the forces while designing. Feeling the forces in an empathic and even sympathetic way is the prerequisite to be able to elevate parametric design towards the level of behavioral design. As a designer one needs to internalize the forces. Information exchange from point to point, from surface to surface basically needs to be seen as streaming information, not just as an instance from a stream. Working with streaming information has an emotional effect on the behavioral designer. Streaming information in relation to the time based instances of 3d modeling is as Spaceland in relation to Flatland, as is the 3d model in relation to the flat geometrical instances of the 2d drawing.

Streaming in both directions, both components need to inform each other continuously about their conditions. For example, when the standing component 1 has varying loads due to changing wind conditions, it needs to transfer the real time dynamic data in a streaming fashion to the supporting horizontally stretched component 2. For a quick understanding of the subject, think of applying such dynamic concept to a one mile high building. Such a high building would normally sweep several meters to left and right and cause nausea for its users of the top floors. Now assume that we build in a series of actuators in the load bearing steel structure, which pro-actively resist to changing wind forces, thus leveling out the influence of the winds. Then the one mile high structure will stand perfectly upright without any movement in the top. It will stand like a human balances in the wind, stressing muscles as to counter the wind. Such a structure would need to send updates in milliseconds as to keep track of the changes, allowing the actuating components to respond and reconfigure accordingly.

One Building One Detail

One building, one detail. I have introduced this challenging phrase in earlier writings [paper for newstandard Praxis, MIT conference, 2004]. Without any reservation I declared: Mies is too Much! Radicalizing the minimalist tendency of Mies van der Rohe, I observed that Mies still needed many different details to prove his point that Less is More. His Less is still too Much. His Less is an imposed Less in visual appearance, but still a More in number of details. For a better performance one single parametric detail must be mapped on all surfaces, subject to a range of parameters rendering the values of the parametric system unique in each local instance, thus creating a visual richness and a variety that is virtually unmatched by any traditional building technique. Such visual richness has been naturally apparent in indigenous architecture, all made by hand, based on simple procedures. Now the new parametric and customization techniques allow such visual richness on the grand scale of large buildings, complexity based on simple rules. Complexity is the real More, based on the truly Less. Please be aware of the double meaning: I do respect Mies van der Rohe to the max, which prohibits myself to copy or vary on the original - it was deliberate violation indeed when Rem Koolhaas forced the Barcelona Pavilion to bend in the early days of his career. Rather one should endeavor to radicalize Mies instead, one should take the next step forward, instead of looking backwards in such incestuous operations. The parametrization of the leading building detail implies an extreme unification, it requires a uncompromising systemic approach, thus allowing for a rich visual diversity at the



Fig. 7

Simply complex, iWEB, Delft, architect ONL [Oosterhuis_Lénárd] 2002 [first life as Web of North-Holland], 2007 [second life as the iWEB].

same time. Les extremes se touchent. The coherence of parts in a parametric design system does not necessarily lead to a harmonic relationship between the parts as suggested by Palladio over 500 years ago, neither as suggested by Vitruvius 2100 years ago. Coherence of parts in a 3d parametric design system covers a much larger bandwidth of possible variations.

The parametric detail is generated just by executing a simple rule, while retrieving local data for each individual node. Simplicity is thus intrinsically tied to multiplicity. Its intelligence is embedded in the swarm behavior of the node, the programmable dot of the informed point cloud. I applied the above one building one detail strategy in the design for the Web of North-Holland [page 10,11]. The whole construct consist of one single but elaborate detail. All details including the two giant doors are members of one big family, described by one single script [Autolisp routine] mapped on the points of the point cloud as distributed on the doubly curved surface of the emotively styled volume.

Just there just then just that

I say no to columns, beams, doors and windows from a standard catalog. Instead of making a tasteful selection from the building catalog, instead of becoming an elit-



Fig. 8

Complicated not complex, Stata Center, Cambridge [USA], architect Gehry Partners 2004.

ist connoisseur of high culture, I am in favor of designing and building project specific building components, for every new building a new consistent set of interlocking building components. It requires no further explanation that the giant door in the WEB of NH, which is basically a cut-out of the building body, is a door in the WEB of NH only, it can not be applied in any other design, it belongs there, does not fit anywhere else, it forms that intrinsic part of that design. Just there, just then, just that. It is the logical consequence of mass-customization that an end product like a door from the standard catalog will not fit anywhere in the newstandard body. In this context I seriously must criticize the buildings of Gehry. From a distance one would be tempted to see them as sculpture buildings, but at closer investigation they are not like that at all, all Gehry's designs are based on traditional spatial planning, like arranging box-like spaces, and wrapping them in the upper floor levels with a decomposed arrangement of loose fragments. Doors, windows, entrances are traditional as ever, 100% based on the technology and esthetics of mass production. There is nothing newstandard about it. Gehry as many of his peers has not been able to loosen the strings to the traditional building industry, they have always relied on stylish catalog products for the majority of their buildings components. They still consider mass production as beautiful. Even when the exteriors of their designs use the metaphor of the newstandard, their insides are full of column grids, beams, doors, walls and windows, all straight from the catalog. They mistake the complicated for the complex. The essence of the newstandard is that each and every building component is precisely defined in the design stage, CNC produced, hence in principle unique in its shape and dimensions. Each building component possesses an unique number to be addressed by the design and engineering scripts. A building component typically is defined as a 3d parametric component that lives in a spatial relationship towards its neighboring components. Mind you, the information that is contained in a 2d drawing can by

definition not give you such information, since the drawings does not refer to components at all, but only to their 2d “flatland” shadows of their 3d “spaceland” information.

The Chicken and the Egg

What came first, the chicken or the egg? My answer to that is just as simple as it is effective: the chicken and the egg are two instances of the same system, meaning that in each stage of development of the chicken-egg system there was both the chicken and the egg. Naturally neither the chicken nor the egg were worthy that name in their early development phase, because they were not that much specified when they were busy developing the earliest versions of the adaptive chicken-egg system. Chicken was more something like a worm, and hardly to be distinguished from their eggs. I assume that self-copying and giving birth were equivalent events before the chicken-egg speciation process took off. There may not be a quick and dirty translation, nor a remodeling, which always will turn out to be a re-interpretation, and there may absolutely not be any human intervention in the nature of the data, which is bound to be the cause of many possible inconsistencies and inaccuracies. Nothing may be lost in translation. The chicken can only produce and lay her own egg herself, the egg can not be produced and assembled by another party applying another systemic logic. Human interventions are bound to blur the consistency, the sloppy accuracy and emotional logic of human measuring or counting simply does not match with the machine logic. Don't worry, I am not trying to exclude people from the process, humans do play the leading role in establishing the concept, in making intuitive choices from a vast multitude of possibilities, in declaring what is beautiful, basically in every aspect of the design and the building process where the communication with other human beings is crucial. But humans are not good at counting, not good in complex calculations, not good in the consistent application of procedures, not good in working overnight. People are always tempted to rethink a procedure while executing it, to rethink a process while running it, typically changing the rules while playing. Also the brains are very slow in calculations, so much slower then the personal number crunchers, their PC mates. In order to catch up with the current societal complexity, which is an ever expanding evolutionary process, the information architect had to develop machinic extensions, exobrains, exomemories, exohands, exoarms and exobodies to design and execute the newstandard designs. That is why newstandard design and file to factories production are two sides of the same coin. There would not exist a truly newstandard design without CNC production, there can not exist chicken without eggs, neither eggs without chicken.

The new role of the newstandard architect

Every analogue intervention in the direct link from newstandard design to CNC manufacturing would compromise the nature of the newstandard design. Examples of such compromises are seen in the making of the Water Cube and the Birds' Nest for the Olympic Games 2008 in Beijing. In such cases the main contractor has chosen to weld the steel structure, hence compromising the accuracy of the structure, and thus breaking the logical link from the complex geometry to a possibly advantageous and consistent file to factory production of the skin. Once compromised, once the chain

is broken, all future steps from there onward can no longer be relinked to the CNC logic of mass customization. The process is killed, the egg is not leading to another life form, the umbilical cord is broken prematurely. Needless to say that each example where the logical chain is broken, is representing a major threat to the practice of newstandard architecture, since the client might only see the blurred outcome and blame the inaccurate compromised details to the nature of the newstandard design itself. But then again, can the contractors and the project developers be blamed to rely on their traditional experience, which is largely based on traditional bricks and mortar buildings? For them the newstandard logic may not be logical at all, they are presumably not familiar with the advantages of the file to factory process, since they are not mastering this process. It is unknown territory for them. Because of the reality of this situation the newstandard designer will need to rethink his contractual position as a consultant only and will need to take on financial responsibility concerning the manufacturing process. Since newstandard architects as myself have full control and full confidence that their data are correct and accurate, they must take on the responsibility for the engineering of the geometry, and naturally must be paid proportionally for this responsibility. The benefit for the building industry will be huge: no more mistakes in the correctness and transfer of the data, no more delays in the exchange and understanding of the concept, remodeling will no longer be necessary, production will be clean and precise, assembly always correct, all steps in the design and building process will be just in time, and just what is needed. No more waste of time and materials, the building site will be clean, while recycling can be developed to cover all used materials. There is one important condition though: all production must be computer numerical controlled, all components must be prefabricated, including all concrete structures, including the foundations. How sustainable can you get? It is obvious that the newstandard architect, who controls the efficiency of the process, must be the first to take profit from that expertise. The appropriate way to effectuate the new role of the architect is to take part in the building process financially. In the present situation architects leave the financial responsibility to project developers and contractors, the architects themselves acting as a consultant only, not being responsible for more then their designers fee. I am an advocate of a new professional attitude of the architect, as to become an entrepreneur, taking over the responsible role of the contractor as for all components that are CNC produced. Architects are chicken if they do not have the guts to claim their leading role as the responsible egg designer>engineer>builder.

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**The Model
and the Spatial Imaginative:
How would it be to Live
in a Soft Space?**

In the early 60s, the French engineer Robert Le Ricolais ran an experimental studio at the University of Pennsylvania. Here, he explored tensile structures for the built environment. Interlacing compressive rings with tensile steel wire, he constructed 'stiff hollow ropes' as structural beams for a lightweight architecture. For Le Ricolais, the structural model was the basis of this investigation. Working to scale, the model allowed him to examine the structural system, develop its detail and test its performance. In a strange laboratory of models and mechanic configurations for cable tightening and load testing, Le Ricolais questioned the material culture of his contemporaries. Exonerating steel from its compressive use, he imagined a near future where steel would be used solely for its tensile properties and in which structure was 'defined through its holes' ¹. Le Ricolais was interested in the automorphic properties of these structures: how scaled self-similarity and material deformation could lead to the imagination of new structural systems. Working for and with redundancy, his focus lay with the reduction of intersections and the proliferation of members in busy networks of material systems. As such, Le Ricolais' work has a textile resonance. His structures examine the tensile logic of minimal surface and the braced friction of a fibre-based construction.



Fig. 1
Thicket installation
at Lisbon Architecture
Triennale.

For Le Ricolais, the model and its testing was a way to engage material performance. The model allowed him to build intuitive understandings of material and structure and to question their interrelationships. Famously, he discussed ‘the beauty of failure’ as a way to understand the relationships between material, structure and form². By testing his hollow columns to the point of failure, he marvelled at the rhythms of stress and their distribution between part and whole. It is the material focus, along with its textile thinking, that makes Le Ricolais’ work especially pertinent for this study.

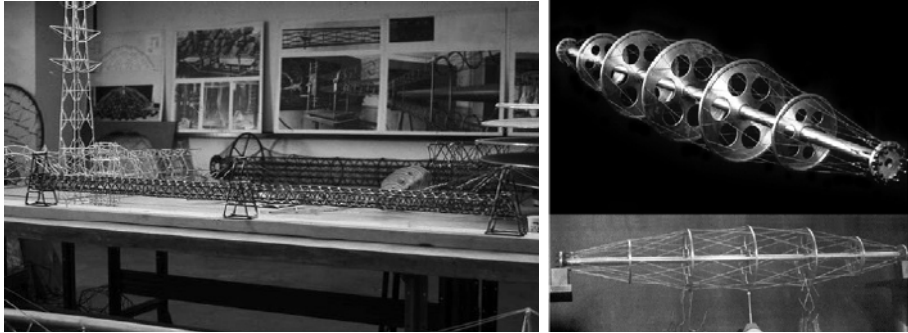


Fig. 2

Photo: Robert Le Ricolais’ studio at the University of Pennsylvania. Structural models.

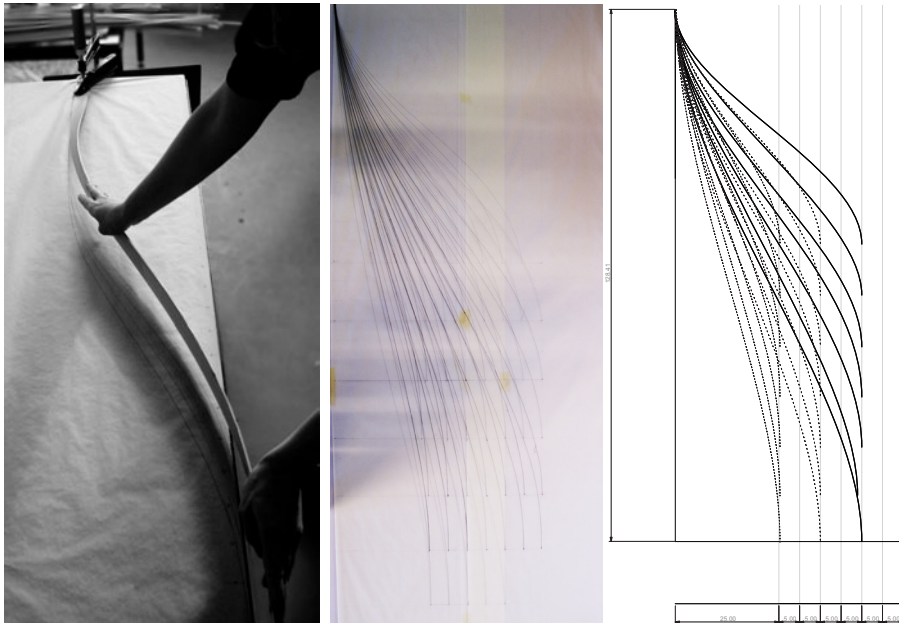


Fig. 3

Measuring and correlating the material behaviour. The tracings of the material deformation define the basis for a simulation of the bending geometry by calculating the changing relationship between length and bend. Constructing data for an informed and structural model.

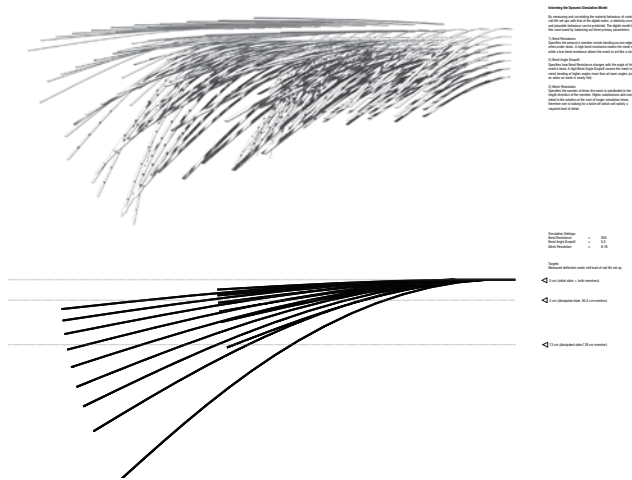


Fig. 4
Drawing: Digital simulation model with measurements and correlations of the material behaviour.

In our work, we position the model as a means of understanding the material reality of our built environment and of probing its possible configuration. Working with material performance, our aim is to imagine how a new material understanding can lead to a new spatial imaginative.

But Le Ricolais' work also bears another relation to the present project. For Le Ricolais, the structural models were also spatial proposals. In an example like the Skyrail project, Le Ricolais and his students imagined a futuristic world in which urban light rail raised over the city like huge pre-tensile stockings would carry 10,000 passengers every hour³. For Le Ricolais, the modelled world encompasses the structural investigation with the urban speculation, leading to the imagination of a new way of living. Here, the material and the spatial are tightly linked in a self-informing loop. Likewise, it is our aim to query this confluence between the structural and the spatially imaginative, the material and the lived.

Introduction

The following discusses the role of the structural model in architectural production. With a focus on architecture as a material practice, our aim is to question how an emphasis on the performative qualities of materials, their ability to stretch, bend and flex, can lead to a rethinking of what a lived environment can be. Through the presentation of the architectural installation Thicket, we will explore the manifold exchanges between tectonic investigation and spatial imagination. Rather than seeking to position material as preceding design, or vice versa, our aim is to understand how the parallel material practices of designing and building resonate and mirror each other and how they come to inform each other.

The structural model as a site of investigation

Architecture is a material practice. In the most profound ways, architecture is about how ideas are embodied. It is this inherent material focus that shapes architectural

thinking, its conceptual frameworks and languages of representation. In architecture the paradox is that this material engagement happens once removed through the mediation of representation and that these representations hold their own material practices: their own matter, technique and craftsmanship by which they are realised. As described by Stan Allen in his essay on the practice of architecture, this mediation between designing and making retains a complex weave of interrelationships that continuously shape each other. Suggesting architecture as a 'promiscuous mixture of the real and the abstract', Allen positions architectural representation as a particular technique, or practice, which in its own right organises and transforms material reality⁴.

In this complex weave, the structural model holds a special position. Being part representation and part material investigation, the structural model questions design at the point of its materialisation. As such, it suggests a particular nearness between the material practices of representation and those of realisation, a nearness formed by the intensified similarity between the material of representation and that of the real. On the one hand, this suggestion is very direct. The structural model aims to simulate material performance and test its ability to stand force. Where other architectural models operate with an abstracted materiality, the structural model necessitates a performative mimicry: for the structural model to be representative, it is critical that its material organisation can be compared to that of its intended realisation. On the other hand, the suggestion of nearness contains a much more convoluted proposition. As the material logic of the model and the realised converge, logic of representation folds into the meaning of the realised. As such, the structural model becomes a place in which the realm of the represented and the potential co-exists with the realised and the present.

A model at 1:1, Thicket and the structural adaptive

In Thicket the model exists at full scale. Developed for the Lisbon Architecture Triennale, Thicket is an architectural installation that explores how structural investigations can lead to the emergence of new spatial thinking⁵. Developing the idea of a soft tectonics, the project asks how the soft and the pliable can be imagined as structural principles for an adaptive architecture. The ideal of the soft is defined on a series of parallel levels that mutually inform each other. Soft is a tectonic material inquiry into the malleable, the crafted and the motile; it is a design inquiry into the definition of variable design representations and it is a cultural question concerning what a home could be.

The project is made in two parts: the installation asks how textile principles of weaving and pleating can define a flexible and breathing architecture while the drawings query the consequences of such a space.

The installation is a 10-meter-high, 10-meter-long structure. Made from pleated ash slats, each member is bent, creating a dense structural network held together by internal structural friction. The lengths of wood are parametrically variegated, creating a differentiation of form. The members are tied together across steel joints and a

series of vertical tension wires pull the structure together. Working with the logic of redundancy, each single member is inherently weak. The load forces move through a field of interconnectivity, creating an overall stiffness in the structure. A pleated textile skin clads the structure, creating a differentiation between enclosure and structure.

Thicket seeks to engage the inherent material pliability of the ash slats. Learning from textile structures of weaving and pleating, Thicket uses self-bracing as a way of generating structural performance. This material engagement creates fundamental changes in the design process. Rather than designing the geometry of the structure and then detailing its realisation, Thicket is defined in a variable design space in which the empirical testing of the curve of the wood as it is forced into bending is encoded into the design. The primary representation is designed as a set of material relationships devising the interconnective field, while its formal presence, the shape and geometry of its outline, becomes a calculated outcome of its material realisation.

The integral weakness in Thicket allows the structure to retain a measure of pliability or softness, allowing it to adjust to changes in its environment or in load. In Thicket this pliability is animated through the introduction of a set of steered pulleys that continually adjust the tension wires. As the tension wires are alternately tightened and relaxed, the structure breathes, creasing its skins in a rhythmic pulse.

The model at full scale

The installation is built at full scale. As a structural investigation, Thicket is both to be understood as a model, engaging the speculative and the testing, and realised, engaging the actual and the lived. But Thicket also holds a more material reasoning for its realisation at full scale. Working for and with material performance creates a particular material hold. The bend of wood is particular to the timber sort and its size and can therefore not be simulated at scale. To design with and for material performance is therefore to design at full scale.

However, Thicket does not fully abandon the space of the model. Instead, it retains an ability to point beyond itself towards a future realisation. But this future realisation is not defined through size or, at a primary level, through material organisation. Instead, it is one of complexity. In Thicket the detailing of the structure and its finishing is understood as place-hold for further development. An example can be seen in the handling of the textile skin cladding. The second skin does not fully solve the question of enclosure. Instead, it provides strategies by which this inquiry can be understood. The presence of the second skin relates the complexity of architecture as multi material and suggests means by which these different material systems can be interfaced. The skin is therefore to be understood as an abstraction, allowing the work a mode of speculation and suggestiveness.

In Thicket the realised becomes its own model. While interrogating its tectonic realisation and questioning its material presence, Thicket is simultaneously a model that points beyond its own realisation towards an implied reality.



Fig. 5
Photo of Thicket, interior view.



Fig. 6
Photo of Thicket, exterior view.

Spatial imaginatives: *How would it be to live in a soft space...*

Where the installation uses full scale to engage with the material performance of a soft tectonics, it also allows for a direct experience of the spatial enclosure suggested by the project. Thicket is large-scale. As a site-specific installation, it has been developed in respect to the large-scale triple height interiors of the Berado Museum that hosted the Lisbon Architecture Triennale. The spaces suggested by the installation are complex densities folding in and out around the inhabitants, inviting them into its pleated interiors. Much more than a simple tectonic inquiry, Thicket is also a spatial probe, questioning what the consequences of this new material practice of working with material performance could be.

It is this inquiry that is unfolded in the accompanying drawings. The drawing set comprises 14 drawings of which 9 are design speculations and 5 are material diagrams detailing the invention of the variable design space. The design speculations draw out the potential spaces embedded in the design system. Inventing its own site, the de-



Fig. 7

Perspective drawing, interior view.

sign speculations hypothesise how the spaces would exist if at the scale of an inhabitable architecture. They query the spatial qualities of the structure both as an inhabited interior as well as part of the contextual thinking of site and an imagined semi-urbanity. Under the title *How would it be to live in a soft space...*, the drawings position the architectures of Thicket at the rim of an excavated ground. Deliberately abstract and exploded into an indeterminate scale, the structure becomes buildings, suggesting the lived space of the high rise. Learning from the utopian projects of the Futurists, Thicket presents the structural investigation as an architecture for an undefined future at an undefined site. But Thicket is not directly a utopian imagination. It does not propose a societal model, nor does it discuss the role of urbanity. Instead, it queries how a tectonic logic affects and changes material culture and how in turn this forms our spatial imaginative. The drawings are therefore parallel to, rather than developments of, the installation. They set up another media correlated to the traditions of paper architecture by which the further thinking of Thicket can take place.

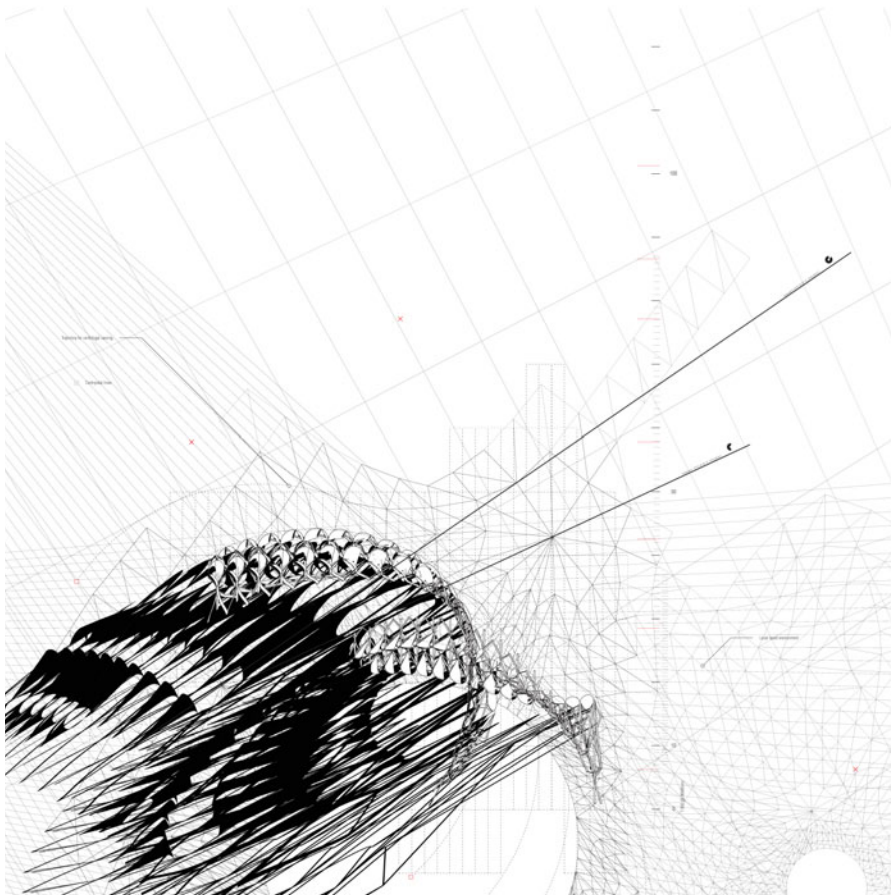


Fig. 8

Plan drawing, adaptive construction in an imaginary landscape. Following page: Perspective drawing, exterior view.

Conclusion

It is this conversation between the traditions of architecture as a means of both material specification and spatial speculation that is at the core of the Thicket project. Thicket is both a structural model as well as an architectural one. Existing at 1:1, it is a model in so far that it contains the imagination of that which lies beyond, which extends from its conceptualisations and technologies of design and manufacture. As such, the project learns from the experimental practice of Le Ricolais in as much as it proposes a reality informed by the material and the tectonic while at the same time imagining how this can change the way we live. Where Le Ricolais' Skyrail project allows him to think of a new infrastructural system for dense urbanity, our aim is to question how a new material sensitivity tuned to the malleable and the shifting – the soft – can lead to an appreciation of architecture as that which is always adapting and changing with its context and site.

The investigation makes use of a series of operations. Firstly, it creates a parallel between model and drawing, allowing them to inform each other while simultaneously retaining an own realm of exploration. Secondly, it works through a deliberation of abstraction. In both the installation as well as in the drawings, abstraction takes place at variable levels, presenting the spatial and structural imagination through partially developed solutions that outline potential strategies for assembly and detail or site engagement and urbanity. So, while negating scale as a sized relationship, the Thicket project retains the model's ambiguous relationship to the fully realised, presenting it without coinciding with it.

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Designing the Seamless and the Scaleless

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**Incipient Movement
Drawing the scaleless
and the seamless**

Becoming architecture. Making body-space-media responsive

The project described in relation to the field of architecture and dance

Influenced by conditions of fluidity and interdependence, performing architecture takes body-space-media resonating as an initial force of becoming. Seamless transfer of information may challenge potentials of digital tools to handle sensible empathic 'invisibilities', making them immediately visible and operative in the process.

Incipient Movement is part of my artistic research work that challenges 'body-presence' in the creation of architecture. The project inscribes itself in a tradition which understands the histories of body and architecture as interwoven in alternating relations. This may be exemplified from Vitruvius' ideal body regulated by geometry until today where the ideal body gives way to differently floating and shifting body-world relations. My work arises from this contemporary body-world 'rhythm', potentially provoking architectural drawing and vice-versa.

Architectonic space limits and orients body movement. Conversely, architecture has the potential of setting free and expanding kinesthetic feeling-out in space. This twist, between oriented movement and movement in its incipiency, is a basic dimension of architectural experience and related to dimensions in dance. Nevertheless this twisting of movement-forces is rather neglected as architectonic design parameters.

Being a recurrent phenomenon, the twist of movement-forces alternates form in different epochs and works. A baroque design, for example, may use these forces explicitly, splitting the kinesthetic sensing between a strong visual dominance of a central axis and a recurrent displacement of an advancing body.

Watching contemporary architecture, this kind of double-movement and kinesthetic ambiguity is harder to point out. An actual 'programmatic/pragmatic' wave, for example, brings a wide range of diverse functions together, say, placing a ski slope on top of a department store. Such functionally complex arrangements may of course provoke the sensory-motor system, but lacks the more subtle kin-esthetic complexity that is a basic part of a body-space vocabulary and a challenge in creating architecture.

Body-space aesthetics engages particular significance in the domain of architecture, different from concepts of body-space in other disciplines, dance for instance. Working as an architect with body-movement, I see a kind of both converted and complementary potential of the two together: architecture working consciously with space as well as more unconsciously with the body, while choreography works consciously with body-movement but is rather unconscious and unspecific about space.

Architecture may use dimensions in dance to get closer to body-space potentials, provoking embodiment aesthetically directly rather than programmatic referentially. The body-scheme normally used in designing is rather poor, lacking embody-mental dimensions in setting up work-modes. Drawing-schemes in general are based as well on primarily two-dimensional conventions of architectural representation. This in spite, digital tools have been around for several decades. Thus, new ways of using contemporary media are almost absent at schools of architecture as well as in architectural firms.

So, a question forces the following issues: Why not consider space as a more plastic and resonating media, challenging responsive forces of becoming architecture along with performing potentials of 'new' media? Why not twist kin-esthetic awareness and provoke conventional body-space schemes? Like 'learning' from Baroque's expanding intensities, not simply copying it, but to transform its subject-centered twist of being, at once symmetrical in front and to the side and imparting a more subject-object resonating performing?

Discussing body-space-media. Exchanging architectural becoming with the field of dance, contemporary media art, and philosophy
Project-concepts discussed and elucidated in cross-relation to concepts drawn from other disciplines

I share conceptions of the body as a creative vector of experimental space-time together with Erin Manning¹ (EM). For my concept of architectonic twists between oriented and incipient movement, I'm in tune with EM's notations about feelings of the incipient potential to move-with the intensity of extension. This concept underlines that movement takes form before actually moving - that movement first gathers in the potential of its incipiency and not in the extensity of displacement.

Working with kinaesthetic empathy I refer to studies of the so-called mirror neurons, the same neurons firing both when an action is performed and when it is witnessed. Constantly enacting at a neural level the actions do not entail seeing something and then responding to it. Resonance occurs prior to any action, enacting the simulation of multiple next responses. Like Susan Foster² (SF) I see kinesthetic simulation of others' actions, as constructing an empathic connection among humans, as an 'a priori' principle that enables social bonding. This simulation goes as well for 'meaningless art movements' – as SF refers to: a conception of dance envisions dance movement as opening the viewer to new moves. Through her own actions as well as those of others, the viewer rehearses and simulates multiple roles, formulating a self, not as an entity that performs an action, but rather as performance itself. By inviting viewers into a specific experience, movement-performance enables us to sense how the body is grounded, how it assimilates technologies for example, so as to change the very definition of the human.

The view below of dancer and choreographer Susan Kozel³ (SK) puts the question: what kind of performative material offers new systems? Not only seen as frictionless supplement of our daily doing, but seen as a creative potential engaging tension-resistance and developing new body-capacities.

SK explicitly uses her experiences as dancer and choreographer, offering perspectives on experience and interaction with an all-over technology, crossing different disciplinary positions in research in new media. She looks at a system's configurations and affordances from the point of view of interplay between mediated and bodily output: 'I see the outputs of media and gesture as a choreography across bodies and hardware/software'. SK brings out the choices taken, dealing with responsive systems, and argues that choice of certain movements among others ascribe a performative dimension to the all-over system: 'The act of filtering out is an act that defines perform-

ance for the purposes of this discussion. Performance can be seen to depend on the preposition 'as': if I choose to see my movement as performance, then it is. Here the 'as' is broadened to include whether we design and calibrate a system to focus a certain kinetic presence or expressive mode: what we deem to be worthy of noticing is the performative, and a ubiquitous system can be a palpable, a performing being'.

Questioning new openings of body-world resonance, created in exchange with digital systems, I also refer to Merete Carlson⁴ (MC). MC examines aesthetic potential in embodied experience of digitally enhanced environments in contemporary media art. She refers to Bernhard Waldenfelt's concept of responsiveness, founded in integration of the different: 'Every thing that addresses us in terms of incitation or appeal reaches us from a distance'. MC considers responsive situations as fields of exchanges relating body and media in more subtle and ambiguous modes, than the straightforward interactive stimulus-response situation we know, say, from most computer games. Exchanging body with digital systems may create strong responsive double sensing in encounters with intensified environments or devices. Responsivity is conceived as an indication of creative receptiveness, founded in integration of the different, giving the phenomenon an embedded state of suspense.

I also use a concept of 'self-movement' as related to kinaesthesia and proprioception, the two systems always acting in connection, but with distinguished nuances. MC describes proprioception referring to stimuli generating sensation of body posture and a relation to one another of body parts, and kinaesthesia referring to sensation of movement as a dynamic unfolded process. The interplay of the two can be challenged as a characteristic quality in a responsive situation, exploring dimensions of body-space relations defined as well from the feeling of the flow or viscosity of movement as from visual input. A challenge in a responsive situation is then to define different dynamic phrases, making use also of non-perspective, non-egocentric dimensions of movement. The dynamic phrases of self-movement may be used as aesthetic potentials. MC cites Maxine Sheets-Johnstone's reasoning about kinaesthetic experience as fundamental for how we experience and understand different movement-forms as space-time organisation of the body in relation to the surroundings, founding basic concepts as well. Kinaesthesia is characteristic for the global force and energy produced in the shifting interplay of temporal and spatial dimensions. Tempo, rhythm and extension characterizing a movement are essential for how we understand our body - and this basic way of making sense is norm-setting also for how we understand our surroundings: 'We make sense of our bodies first and foremost. We make sense of them in and through movement, in and through animation. Moreover we do so without words. This primordial making sense is the standard upon which our sense-making of the world unfolds'.

Philosophically my project is framed by a chiasm of aspects of phenomenology related to Merleau-Ponty and post-structuralism related to Gilles Deleuze. Aware of the controversies of this stand, I again wish to quote Susan Kozel⁵ (SK) who explicitly works with a synthesis of the two, being aware of problems set up by such a manoeuvre. SK: 'a drawing together of Deleuze and Merleau-Ponty may seem paradoxical or even blasphemous to the faithful from both sides. Merleau-Ponty seems to hold sacred the form of the human body, while Deleuze disintegrates it into forces, planes and directions.

My kinetic corporeal expansion of Merleau-Ponty is twinned with a phenomenological twist on Deleuze'. Also Brian Massumi⁶ (BM) relates the two philosophical stands, stating: 'there is no effect without an accompanying movement in or by the body'. And BM points out that it is in the understanding of embodiment you find the fracture/fault line between a phenomenological and a Spinoza-Deleuzian inspired approach.

Merleau-Ponty's (MP) late works constitutes the subject as a continuing reversible dynamic being between interior/exterior, body/surrounding-world, passive/active. MP works with a concept of creative receptiveness, trying to resolve the dualism of subject and object, of feeling and felt. But doing so, he makes no room for explorations of the basic tension between the two poles. MP as well works with a concept of body-scheme, characterizing the body as a pre-reflective space of potentiality that constitutes our perception of the outer world. Anchoring the body-scheme in proprioceptive sensing, the scheme is seen as a system of movement- and posture functions, functioning independently of perceptions of the body seen from outside. Making proprioception central as a non-perspective sensation, marks this (internal) concept of body-scheme as different from (external) concepts of body-images often related to it.

Gilles Deleuze's (GD) conception of bodies as a mixed assembly of forces and planes rather than understood as a subject, is extracted below in a very condensed form. GD defines bodies and thoughts as capacities for affecting and being affected. He defines an animal or a human being not by its form, its organs and its functions and not as subject either; he defines it by the affects of which it is capable. An affect or an action that one body produces on another body always implies a contact, even a mixture of bodies. Affection then is a mixture of two bodies, one that is said to act on the other, and the other receiving the traces of the first.

Setting-up components, dynamic phrases- and modes of operation Work-forms reflected in relation to concepts and to figures/sequences 1-4

Embodiment-mental sensing and taking-form resonate in my project-setup as series of relations between simple tectonic/topological forces and forces of body-movement. Using media responsively the work twists body-space creation, exchanging the actual time-space-depth of a participator with virtual time-space-depth of transformation and deformation of drawing.

Setting up a responsive situation, the concept of 'drawing' is taken literally and series of drawing-material are projected on a vertical surface. At the same time the drawing-surface is 'broken up', defining a horizontal field of self-movement. Stepping into the situation the moves of a participators are 'captured' by four cameras, able to read tempo, orientation and acceleration multi-laterally. The dynamic qualities are made accessible and relate to different drawing layers and sequences of projections.

The paper presents frames from one of four series. This series relates forces of stacking and upwards/downwards oriented movement, presently worked out as a film-sequence. In the following I will relate to this series, making the frames present a kind of storyboard which points out key-responsive components and phrases. Drawing-material is composed as an assembled field of resonance, organising different component in different layers and sequences. The frames below are disposed in three layers of in-

dividual components, work-forms and tempers. Furthermore it is organized in four sequences, responding to different choices and rhythms of the participator:

Layer1 articulates and deforms atmospheres, modelling and animating fractals of light-space. The fractals are constructed in different series and phrases: 1, as a 'landscape' or 'map' slowly looping, 2, as tectonic key-fractals rising and falling, 3, as fractal-swarms intensifying and expanding, and 4, as fractal-thresholds spinning upwards and downwards.

Layer2 draws and transforms lines and traces, pointing out diagrammatic motives. The line-figures combine feel of territory and orientation; they stretch out or bend back upon themselves, tracing expanding or enclosing qualities, and offers the participator orienting 'arrows' and 'grips'. The line-figures loop rhythmically between different force-orientations, as 'step stones' arbitrary related to the changing atmospheres - in contrast to the atmospheric layer-sequences triggered by participators moves. Line-forces measures rhythm and transgress conventional concepts of surface and depth; they provoke locally cut-ups of atmospheres and opens for intruding characters or inserts of 'foreign bodies'.

Layer3 inserts foreign bodies as local disturbances and 'arrows' as well as indicators of incipient moves. Edited/abstracted motion-captures of selected movements of the participator are inserted, generating new rhythms and narratives. They trigger lines and staple-points that relate the 'foreign body' to motives and local components of the drawing.

Sequence1 is from an initial phrase, the field being in a trance, presenting atmosphere as a kind of dynamic 'landscape' or 'map'. Participator's entrance in the marked horizontal field fires the tectonic key-fractal, rising and falling in its own steady rhythm.

Sequence2 make the participator proceed and get closer to the drawing/projection surface; now his all-over moves begin to resonate with the key-fractal rhythm, the fractal's tempo and temper being responsive to participator's self-movements. This move also triggers tectonic line-figures, tracing forces of dive into or lift up; and fires the fractal-swarm. Responding to the swarm, the participator now has to be more move-specific and use upward and downward oriented movement to let the swarm take off and ascend or dive. At the same time these synchronous movements are ambiguous. The atmospheric fractal-swarm has its 'own life' and tensions as well, seeking to intensify and/or expand the force-fields of the line-figures by animating and deforming the fractals individually or in small groups. This enacting both strengths and breaks open tectonic forces of the drawing field.

Sequence3 convert these tensions and ambiguities triggering possible fractal-thresholds. These atmospheric fractal-thresholds spin upwards and downwards, now synchronous with participator's rising and falling movement. Now the tension emerges between the fractal-swarm's searching flow and velocity and the characters offered by the spinning thresholds.

Sequence4 changes the orientation of self-movement, now focusing tensions between shifting points of view. Hereby the spinning movement of the fractal-thresholds is left alone; it is overlaid by locally inserted series of lines, making the participator scents

forces of depth ambiguously. Again using his all-over movement simply to get closer or withdraw, and also drawn by the double-exposure of her own abstracted movement, the participator triggers a zoom-into an interval of the spinning atmospheric space-figure. The zoom-in produces a freeze-frame in slow expansion, over-layering the space-figure's spin around its own axis. Simultaneously the zoom-in affects the sensing of line-figures, looping rhythmically between different force-orientations and 'step stones' arbitrary related to the changes of the atmospheric space-figures. The effect is an ambiguous deforming but resonating depth-orientation. Showing up in intervals between the twisted space-depth of the zoom-ins, the abstracted movement of the participator may mingle with bodies of the swarm and create an expanding and condensing rhythm and another kind of 'measuring' than the scale representing body of conventional drawing.

Figures/sequences1-4

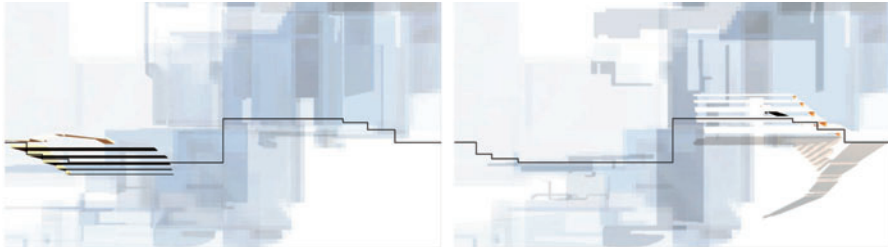


Figure1/Sequence1

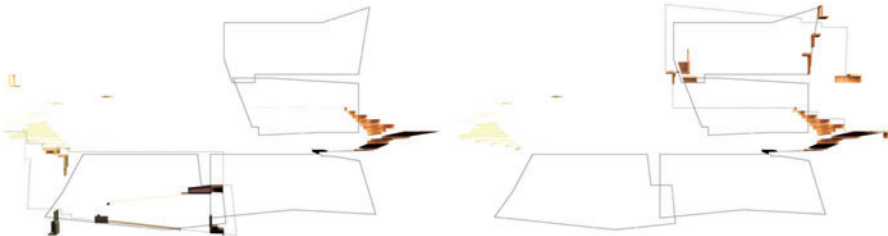


Figure2/Sequence2

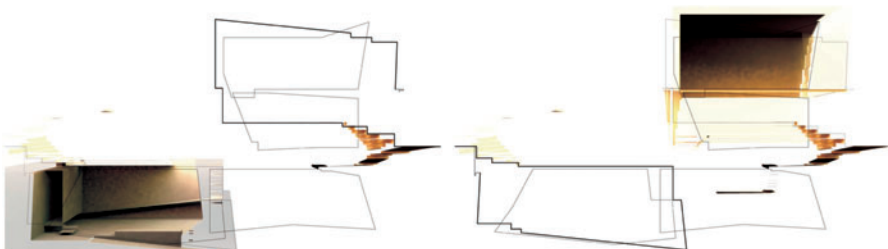


Figure3/sequence3

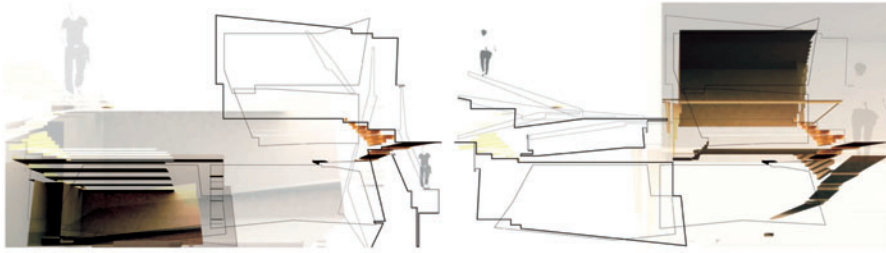


Figure4/Sequence4

Conclusion

Double-aim as artistic research and as related to architectural education

The project is double-oriented and both issues are handled with the same responsive strategies. As artistic research it produces artwork, as well as reflections about exploration of responsive body-space-media strategies of architectonic becoming – this is the line of the actual paper. Parallel, aspects of the work are to be discussed in a context of architectural education, provoked by the adherence to conventional architectural drawing, prevalent at many schools of architecture.

Using contemporary media, there is a surprising lack of experimentation at schools. Explorative drawing engaged with multisensory capacities of the body should be a basic discipline, investigating/trying out aesthetic-ethic dimensions of composition that touch the very definition of the human. How to draw new body-space? How to involve new strategies and reflections in the more 'hands-on' drawing-situations of education? My project is engaged also in coupling new and conventional tools, provoking exchanges and resonance between different kinds of information and sensation, which different work-forms may produce.

Teaching as well as creating architecture, you may challenge the drawing as presentation opposing re-presentation – engage forces and material of becoming in the artwork itself. In exploring body-space you may generate modes-of-operations that sensualise colliding questions and provisional hypothesis and challenge the aesthetic-ethic dimension of composition – attempting to perform a less fragmented architecture and its education.

Notes

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**Generative Approaches
in Tower Design**

**Algorithms for the Integration
of Tower Subsystems**

Introduction

*"Not only biology has become indispensable for building but building for biology."*¹
Frei Otto

The tower² typology preserves the vision and ambitions of modern cultural and technological production. As the symbol of Modernism, the tower agenda is still defined today by standardization, repetition, segmentation, and orthogonal grid based structures. This agenda has instigated the potential of the tower to be reduced to binary axioms, such as tower and city, circulation and habitation, structure and skin.³ Combined with the global economic and cultural motives for the tower, which are emphasized through parameters such as dense urban contexts, high real estate values, commercial opportunity, corporate demand, and iconic presence, the tower has become a self-referential object that has limited connection to its urban context.

In contemporary urban conditions, where the various social, economic, cultural and artistic systems are interacting in a constant flux of density and differentiation, the tower needs to respond to its current environment by changing from a closed building typology of repetitive floor plates towards a heterogeneous, differentiated open system that can adapt to the changing conditions surrounding it. Whether it is programmed for a single function or multiple uses, the contemporary paradigm of architecture will expect a differentiation of the tower along its vertical axis, its circumference, and within its volume that are interdependent with each other.

"Generative Processes in Tower Design" focuses on the principles of biological models in order to propose computationally generated dynamic systems for the tower typology, with the aim of achieving an integrated model for the tower subsystems that can coherently adapt to their climatic and cultural context.

Tall buildings originated at the end of the 19th century in the United States of America, more specifically New York and Chicago, as a response to the high demand for commercial office usage. Since then, this building type has spread across the world, especially in the Middle East and Asian countries, such as China, Korea, Japan, and Malaysia. Whereas 49% of tall buildings were located in North America during 1980's, currently Asia has the largest share tall building distribution with 32%. The programmatic features of the tall buildings have also shifted throughout the progression of tall building design and construction, with the introduction of mixed-use, residential, and hotel usages in addition to offices.⁴

The development of tall buildings in contemporary practices relates closely with structural developments. This is due to the fact that 'tallness' amplifies the significance of different loading conditions that act on a building. Due to the impact of loading in tall buildings, the structure of a tall building bears a significant role from the outset of the design process. In comparison with lower buildings, tall buildings are exposed to higher vertical loads, and more importantly higher lateral loads, mainly due to the wind stresses. The primary structural skeleton of tall building acts as a vertical cantilever beam with its base fixed on the ground.

Within the context of this research, tower is understood as a building system under considerable lateral loading conditions, with slenderness ratio ranging between six to eight. The focus is based on treating the tower as an inhabitable structure, whereby its footprint and internal spatial organization should allow for various programmatic requirements. In this respect, the correlation of footprint to height and how this correlation is influenced by lateral loading become more influential in the design research process rather than stating a predetermined height for the tower.

Current State of the Tower

From the end of the 19th century till the 1960s, the common practice of constructing tall buildings was the rigid frame with wind bracing, which resulted in the over-design of structure due to the excessive use of structural material, thereby causing it economically not feasible. Structural engineer and architect Fazlur Khan introduced the notion of the 'premium for height' for tall buildings in 1960's, and in 1969 classified their structural systems in relation to various techniques of resisting lateral loads for steel and concrete buildings. This initial classification according to different material systems introduced for the very first time a differentiated approach into examining tower structural systems with the aim of increasing tallness and stiffness while decreasing the amount of material. Due to the developments in structural systems in the last decades in conjunction with progressive material systems, construction technologies, and computer simulations, a refined classification has been proposed by Mir M. Ali and Kyoung Sun Moon, based on the first classification proposed by Khan. Accordingly, structural systems for tall buildings can be divided into two categories: interior structures and exterior structures.⁵

The development of tower structural systems reveals that even though there has been a continuous differentiation of material organization with the purpose of increasing height and rigidity simultaneously by decreasing material usage, each distinct tower system has a homogeneous and repetitive organization. The structural loading along the height of the tower varies drastically from bottom to top; however, the change in loading conditions is not reflected along the vertical axis of the tower as formal topological variation. This rigid and repetitive modality, characteristic of the Modernistic paradigm, has prevented any kind of rational transition within a specific type of tower structural system.

Furthermore, the notion of differentiation has not been integrated with the other subsystems of the tower. The differentiation of material organization in the tower structure has been limited to one subsystem only, the structure. As such, tower structural systems have developed with single objective optimization. Other performance related capacities, such as circulation, facade, and environmental aspects, have developed independently of the material organization of the tower structure. Moreover, the tower structure has become devoid of responding to the spatial differentiation that takes place within, acting merely as a homogenous container. It has not responded to the changes and shifts in its programmatic diversity, which in effect influences circulation, facade-related, and environmental differentiation. This additive approach, where each subsystem is considered as a separate layer, results in the inefficient and excessive use

of tower material organization. In this regard, the current knowledge on tower design lacks an integrated approach towards its subsystems on two major levels, the first being the “topological variation” within one subsystem, and the second being the “inter-system differentiation” taking place between multiple systems. Therefore, it is necessary to explore and learn from existing systems which are capable of integration and co-adaptation.

The current organization of the tower subsystems, which are classified into five groups as the structural skeleton, habitable surfaces, circulation/navigation system, envelope, and environmental systems, have developed in an independent manner. The subsystems are partially related to each other in terms of taking minor secondary functionalities that primarily belong to another subsystem, as in the case of floor slabs having additional structural capacity. However, the potential of the additional capacity has not been exploited such that it can become a fully integrated part of the primary subsystem. As such, the conflation between the subsystems needs to be analyzed and explored with an innovative vision.

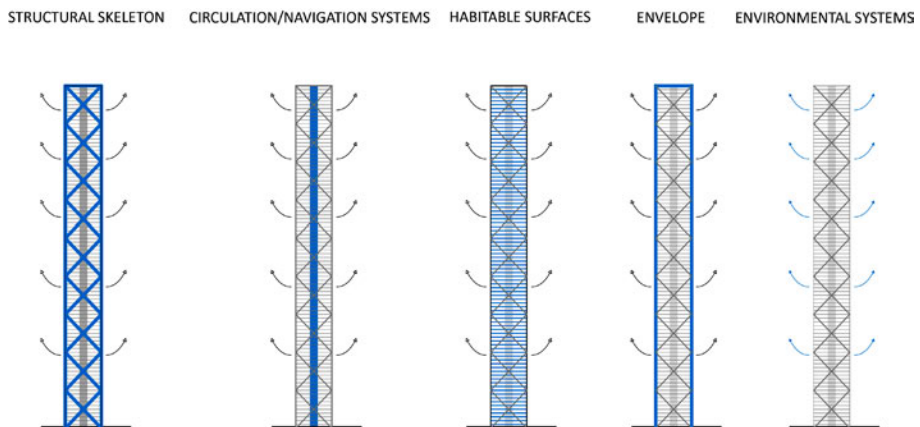


Fig. 1
Tower subsystems.

Biology in Architecture

There has been a broad body of research work on the relationship between nature and architecture throughout history. Biology particularly serves as a main resource for architecture due to the strong relationship between form, material, and function in its inherent formation. The analogies between biology and architecture can be classified into two groups, the first acting as the mimicry of biological forms and the second acting as the mimicry of biological materials, structures, and processes.⁶ Within the context of this research, processes of self-organization and material configurations have been examined as analogous models towards the generation of an integrated approach for tower subsystems.

Natural systems are complex organizations, characterized by the spontaneous emergence of interdependent subsystems, ranging from the cellular to the global level that can adapt to various external stimuli. The subsystems can carry on distinct functions at once due to the principles of differentiation and redundancy. In the case of plants, the plant stem can undertake structural, transportation, and storage functions due to the variation of its sections along its length and the ordering of its basic materials into complex hierarchical arrangements. The organization of materials in interrelated semi-autonomous hierarchies by means of redundancy and differentiation leads to the integration of distinct functional systems throughout the stem. On the contrary, in current architectural practices, the sub-systems of the tower, such as façade, structure, floors, roof, services, carry on specific functions. These subsystems are separated from each other with boundaries and joints which prevent the material and functional continuity between them. The subsystems mostly perform their entitled functions; they do not have the balancing capacity of executing additional tasks, whereby they can only act as homogeneous entities.

In natural systems, form, structure, material, and function have an intricate relationship with each other.⁷ One cannot calculate the behavior of any one of these properties without analyzing the other properties, since they are highly linked at every level of the biological system during self-organization. In this process, all of the lower-level systems and material organizations carry equal amount of vitality for the survival of the whole natural system. The genetic code bears information for the self-generation of its form in relation to the environment, pointing to the fact that the processes necessary for the material organizations to carry on distinct functions at once is inherent in the encoding of the cells themselves. Similarly, the correlation between form, structure, material, and function should be articulated in the tower typology by devising a system which is ruled by parameters relating to its structural, formal, performative, ecological, and contextual qualities.

Regarding the above mentioned explorations as a foundation for the research area, specific biological analogies which have been studied in this work include the mechanical properties of the bamboo stem and the geometrical properties of minimal detours systems. The common feature that these models share is their property of self-organization as well as their unique geometrical and structural properties.

Mechanical Properties of Bamboo Stem

The mechanical properties of the bamboo stem prove to be beneficial for the tower structural system in various ways. Bamboo is formed of long cellulose fibers embedded in a ligneous matrix. The fiber distribution along the bamboo stem is differentiated along the height and circumference; the distribution of fibers is more uniform at the base compared with the middle and top portions. This occurrence can be explained by the fact that bamboo needs to carry maximum bending stress caused by wind and its own weight at the base.⁸ The radial differentiation of fibre density, increasing from centre to periphery matches the distribution of bending stresses. The phenomenon of differentiated distribution of fibers according to applied forces can

serve as a model for the distribution of structural members of towers along the vertical axis and the circumference.

The bamboo stem comprises internodes and nodes. The stem itself is a hollow cylindrical shell along which the nodes correspond to the internal diaphragms, described as transversal connectors located throughout the height of the bamboo stem. The diameter of the stem changes slightly at the nodes, which also function as location for new growth. Internodes are located in between the nodes, denoting the hollow portions surrounded by the culm wall. The diaphragms supply resistance against the buckling of culm wall over the height of the stem. There are two major outcomes of the material in the stem being positioned at the outermost location from the vertical axis. The material deposition enables greatest bending resistance as well as causing gravity loads to be carried only on the outside skin of the stem, minimizing overall weight and preventing uplift due to lateral loads.⁹

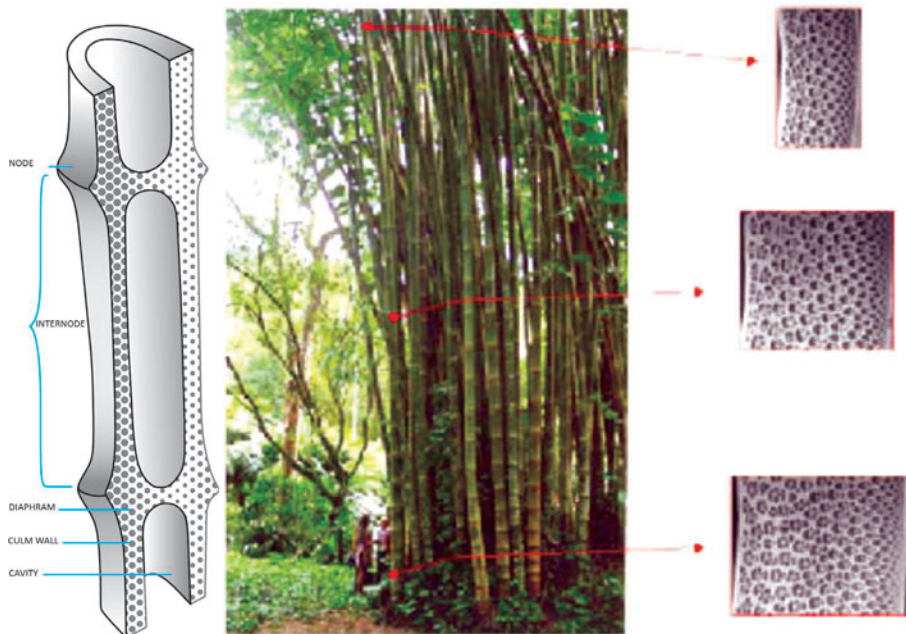


Fig. 2
Bamboo cross section and horizontal sections.

The position of the diaphragms, internode diameter, and the culm wall thickness are dependent on each other. The geometric relationships between these entities have been described by Jules Janssen.¹⁰ The equations below summarize the correlations which can be observed in many bamboo species:¹¹

Internode Number

$$x_n = n \times 100 \div N$$

Internode Length

$$y_{n1} = 25.13 + 4.8080 x_n - 0.0774 x_n^2 \text{ (below mid-height)}$$

$$y_{n2} = 178.84 - 2.3927 x_n + 0.0068 x_n^2 \text{ (above mid-height)}$$

Internode Diameter

$$d_{n1} = 97.5 + 0.212 x_n + 0.016 x_n^2 \text{ (below mid-height)}$$

$$d_{n2} = 178.84 - 2.3927 x_n + 0.0068 x_n^2 \text{ (above mid-height)}$$

Wall Thickness

$$t = 35 + 0.0181 (x_n - 35)^{1.9}$$

Fig. 3

Equations for the bamboo stem.

In these equations, x_n is the internode number, n is a shaping parameter; N is the height of the structure; y_n is the internode length; d_n is the internode diameter; t is the wall thickness. The information embedded in these relationships can be generalized in relation to the various forces the bamboo is subjected to. As the lateral loading condition and the weight from gravity is highest at the base of the stem, the internode heights at the base become shorter than the mid-height. As such, smaller internode heights increase moment-carrying capacity and buckling resistance. Above the mid-height of the culm, the internode heights decrease once more in proportion to the internode diameter as a reaction to increasing lateral loads.¹²

The above-described morphological relationships of bamboo are applied to the structure of the tower on a global scale. The diaphragms of the bamboo stem can serve as an analogous model for an outrigger system in a tower. The position and the diameters of the outriggers can be predicted by using the above equations in order to resist lateral loading conditions in an effective manner. Moreover, the structural members of the tower can be differentiated in terms of amount and sectional size with regards to the changing loading conditions. However, a significant difference needs to be noted when the diaphragms of the bamboo are to be regarded as an analogous model to the outriggers of the tower. As an inhabitable structure, the tower is also under the effect of live loads, a dynamic type of load which is dependent on building use, such as human movements and snow loads. In this respect, since the outriggers are also exposed to live loads, their fibers/ structural members need to be designed by taking into consideration this extra loading condition.

Minimal Detours System

Extensive research on branching structures has been pioneered by Frei Otto and his team as the 'Biology and Building' Working Group at the Institute for Lightweight Structures, Stuttgart University during the end of 1980's. The focus of this research has been to investigate the potential ways of covering large spans with optimized

branched constructions. In this study, concentration has been kept on regulating the material organization of the system as a direct outcome of the force fields acting upon it, so that the load bearing capacity is increased while the amount of material deposition is decreased. As such, form-finding was investigated as a "single objective optimization".¹³

Branched constructions can be described as three dimensional supporting structures used in various material systems, such as steel, wood, and concrete. This structural system offers more stability than conventional beam structures as beam structures are more likely to overturn as a result of wind and earthquakes. Moreover, the use of branched structures enables the use of thinner structural members and covering larger spans.¹⁴

The properties of branched constructions have been explored by Frei Otto and his team in order to formulate methods of transporting forces over a given distance in the most effective way. The first method, minimal path system, links given points with detours to produce the least overall distance. In nature, the minimal path system can be observed in the self-formation of soap films. Structurally, this system is less effective for the transport of forces as the outer support arms are loaded in bending. The second method, direct path system, connects every given point with a straight line to each other with no detours. Through this method, the forces are transported on the shortest possible path, but the overall path length increases drastically. This system becomes more effective if the points of force application are connected with beam ties so that the bars are compression loaded. The third method, namely the minimal detours system, can be viewed as a negotiation between the minimal path and the direct path systems. Synthetic analogy research about this method has been carried out by exploring the self-formation processes in moistened thread networks. Reviewing this method in a structural context yields the result that the forces to be transported are more optimized due to the concentration of paths, increasing the buckling resistance of structural members. Effectiveness of the system is increased more if the points of force application are connected with a beam tie. As a result, branched structures generated with minimal detours system use less material in a more effective manner than the ones generated with direct path system.¹⁵

In nature, branched structures can be found in abundance throughout various plant systems. Materialized direct path systems can be observed in umbels, and materialized minimal detours systems can be viewed in bushes and shrubs. The difference between branched constructions in architecture and nature lies in functionality. Whereas the branched structures built by humans are mainly designed to carry a structural function, the branched constructions of nature have the property of multi-functionality. In the case of plants, the branches need to transport water, minerals and products of photosynthesis for survival as well as maintain the necessary structural resistance against the various forces applied to the leaves.¹⁶

The combination of the effective properties of the minimal detours system and the multi-functional quality found in natural branched constructions can be merged to serve as an analogous model for the structural components of the tower. Follow-

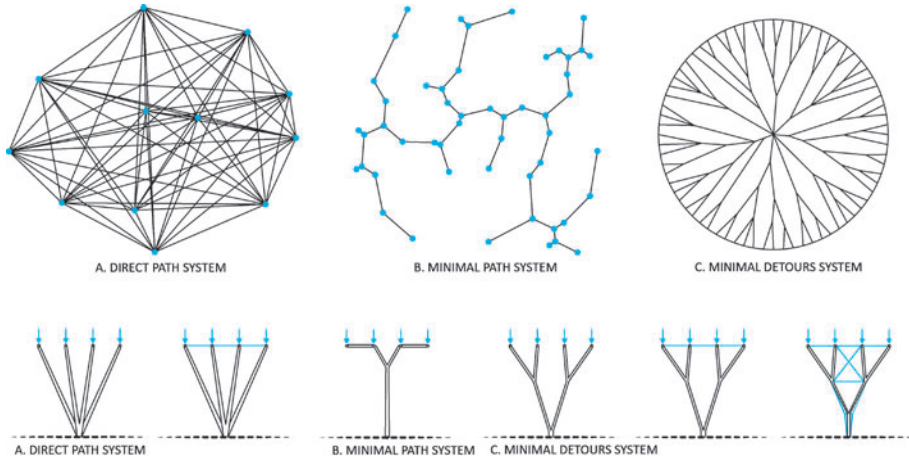


Fig. 4
Differences between optimized path systems.

ing the global geometrical rules of the bamboo stem described above, the structural members can be defined geometrically in relation to the mathematical rules of branching systems in order to devise a design method where the organization of structural members is set up to resist the loading conditions of the tower in the most effective way. As such, a hierarchical design system is proposed where the properties of the bamboo stem and the properties of branching structures are integrated on different levels.

Computational Model

The organizational layout for the design explorations aims at creating a hierarchical framework towards the integration of the tower subsystems. In this respect, integration methods of the subsystems have been explored at the outset of design experiments. The conventional methodology of subsystem association is termed as 'cascade of individual subsystems'. This method forms the default mode of architectural production today and points out to the additive approach where each system is treated as a separate entity. The parameters of individual subsystems have scarcely any correlation with each other. The second methodology, 'multi-parameter integration', is an ideal setup where the various parameters of all subsystems would be in a constant flux of correlation through their defined interdependencies and multiple feedback mechanisms. This methodology proves to be too complex with regards to the organizational and computational aspects owing to the overload of simultaneous different parameters. The third methodology, 'clusters of subsystems', can be viewed as a negotiation between 'cascade of individual subsystems' and 'multi-parameter integration'. In this arrangement, the subsystems of the tower are clustered into two main groups. The first group comprises of the structure, habitable surfaces, and the vertical circulation. The second group includes the structure, façade, and the environmental sys-

tems. Initially, each of the main groups are generated and analyzed with their respective subsystem parameters. This setup allows for the generation of interdependencies among various subsystems without handling excessive amount of parameters. Since both groups share the structure as their mutual subsystem, they bear the potential of convergence and overall analysis in order to generate a total integration of tower subsystems.

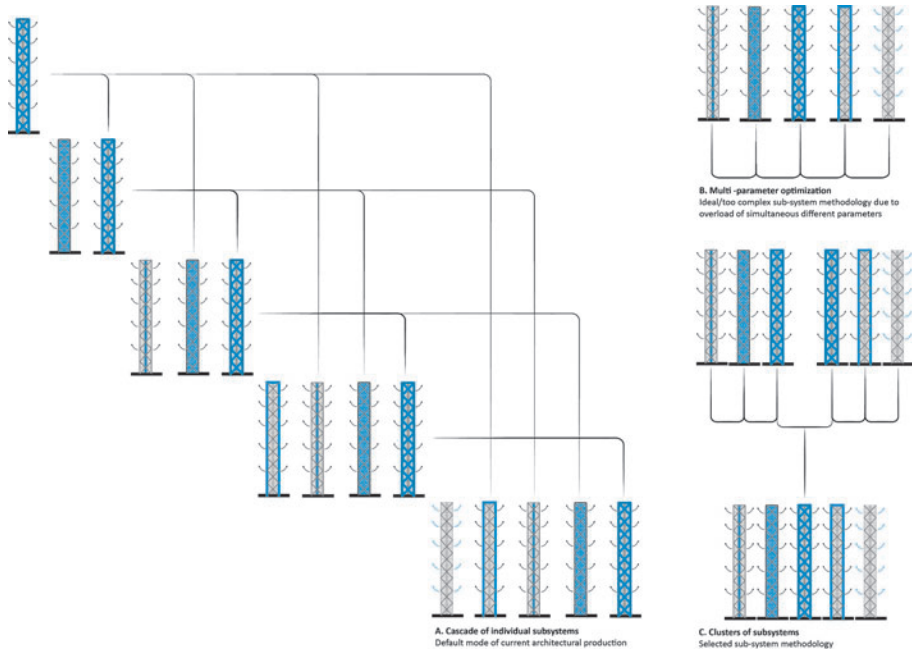


Fig. 5
Subsystem integration methods.

The design explorations are governed on a global level by the programmatic and massing parameters. The tower's internal spatial organization, vertical circulation, and external periphery need to respond and differentiate according to the design constraints of office, residential, hotel, and mixed-use programmes. These design constraints are coupled with the various massing options, which are namely solitary tower, family of towers, branching towers, and towers with a podium. The ongoing research is currently focused on the integration techniques of the first group of subsystems (structure, habitable surfaces, circulation) within a solitary tower which can accommodate mixed-use programmes.

The computational setup for the design explorations reflects the characteristics of self-organization described above through various biological models. As a systematic approach, in biological systems self-organization refers to the process where pattern at the global level emerges from the interaction between lower-level components. The rules specifying the interactions between lower-level components rise from local

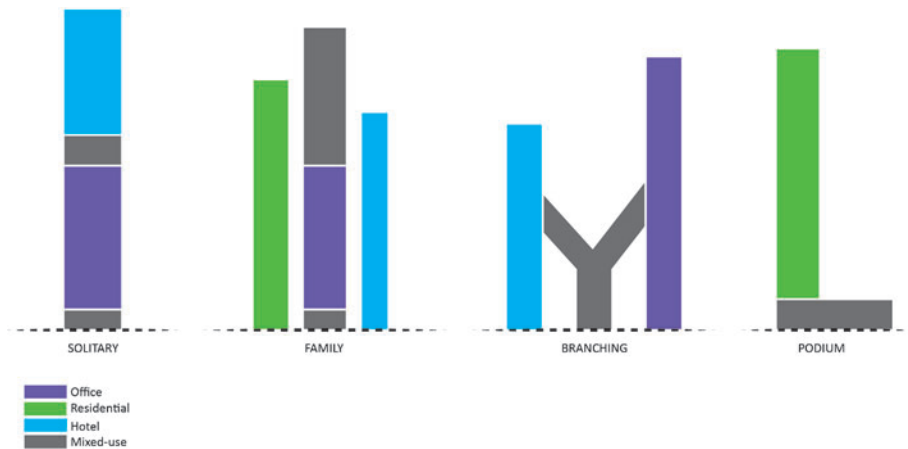


Fig. 6
Programmatic and massing design constraints.

information, without the interference of external directing instructions. The transition of this phenomenon from the biological world to the digital paradigm has been realized by swarm intelligence. Swarm intelligence describes the behavior exerted by natural or artificial self-organized systems, which are made up of boids/agents interacting locally with one other and their environment. These interactions lead to the emergence of complex systems demonstrating intelligent behavior on a global level. The simulation of swarm intelligence is realized by agent-based models, which are computational algorithms created to simulate the interactions of local boids/agents in order to evaluate their complex behavior. The term “boid” was first coined by Craig Reynolds in 1986 when he created a flocking algorithm for generic creatures.

An agent-based model has been devised for tower design explorations in the open source environment Processing. As an object-oriented programming language (OOP), Processing allows for the generation of procedures / objects on a local level (class) which can then be interacted with each other according to a set rules in order to produce emergent patterns on a global level. In this respect, initially the global geometrical constraints have been defined through the setting of the slenderness ratio, which can range from six to eight. The height of the tower is calculated according to the defined base radius and slenderness ratio. On a local level, all the agents in the system interact with each other according to flocking principles, namely separation, alignment, and cohesion. Additional flocking rules in relation to the vertical speed of growth and rotational force of agents are assigned.

The primary agent setup is comprised of two sets of agent groups which form two helical intertwined structural frames. The main motive behind creating two structural frames instead of a singular one is to infuse the structures with differentiation and redundancy by assigning related but discrete functionalities to each of them. Moreover, a double structural frame bears the potential of generating different spatial configurations in relation to the frequency and location of intertwining.

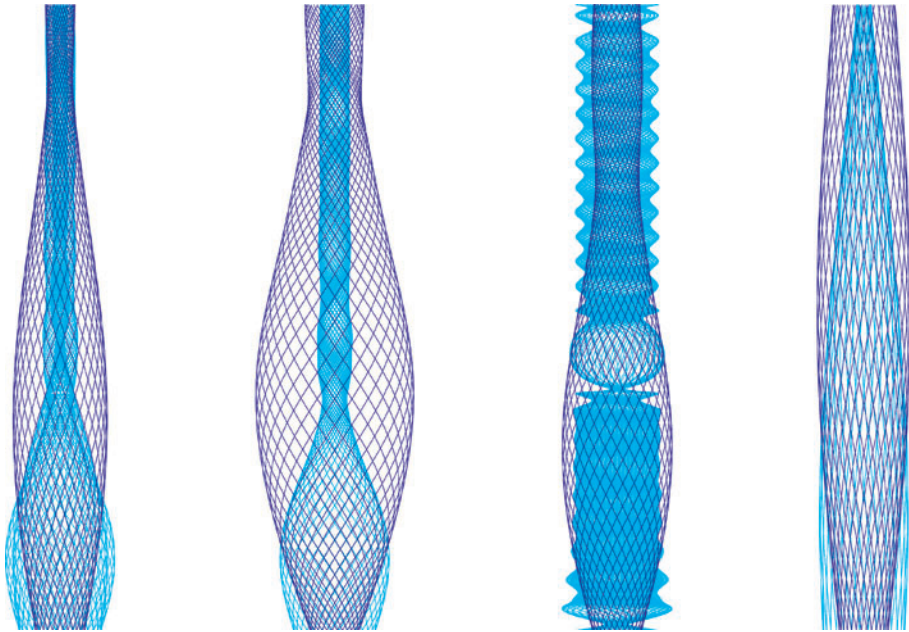


Fig. 7

Formal explorations showing double structural framework.

The helical double structure serves as a major framework for the generation of floor slab members, outriggers, and vertical circulation. As the agents grow vertically to form the double structure, they branch out to form the floor slabs using the specified floor heights for discrete programmes. The positioning of the outriggers throughout the height of the tower is defined according to the above described geometrical relationship between the bamboo stem internodes and heights. The outriggers serve to connect the external and internal structural frames, whereas the floor slabs are tied to the internal structure. While the external and internal structures act in compression, the floor slabs and outriggers act in tension. The double structure and the floor slabs / outriggers are interdependent systems, meaning the floor slabs and outriggers prevent the double structure from collapsing while the double structure, in turn, supports these horizontal members. The vertical circulation members inhabit the space in between the external and internal structures, generating a spiraling circulation space which can be envisioned to serve with rotating escalators. The vertical circulation members are also tied to the double structure framework, facilitating to stabilize the overall structure further. Since the distribution of loads takes place over the entire fibrous members of the tower, vertical elevators can be located throughout the floor plate in desired locations. This approach, where the structure, floor plates, and circulation systems are generated together in a seamless fibrous fashion, presents a significant shift from the traditional method of relying on a rigid internal core and a series of columns for stability.

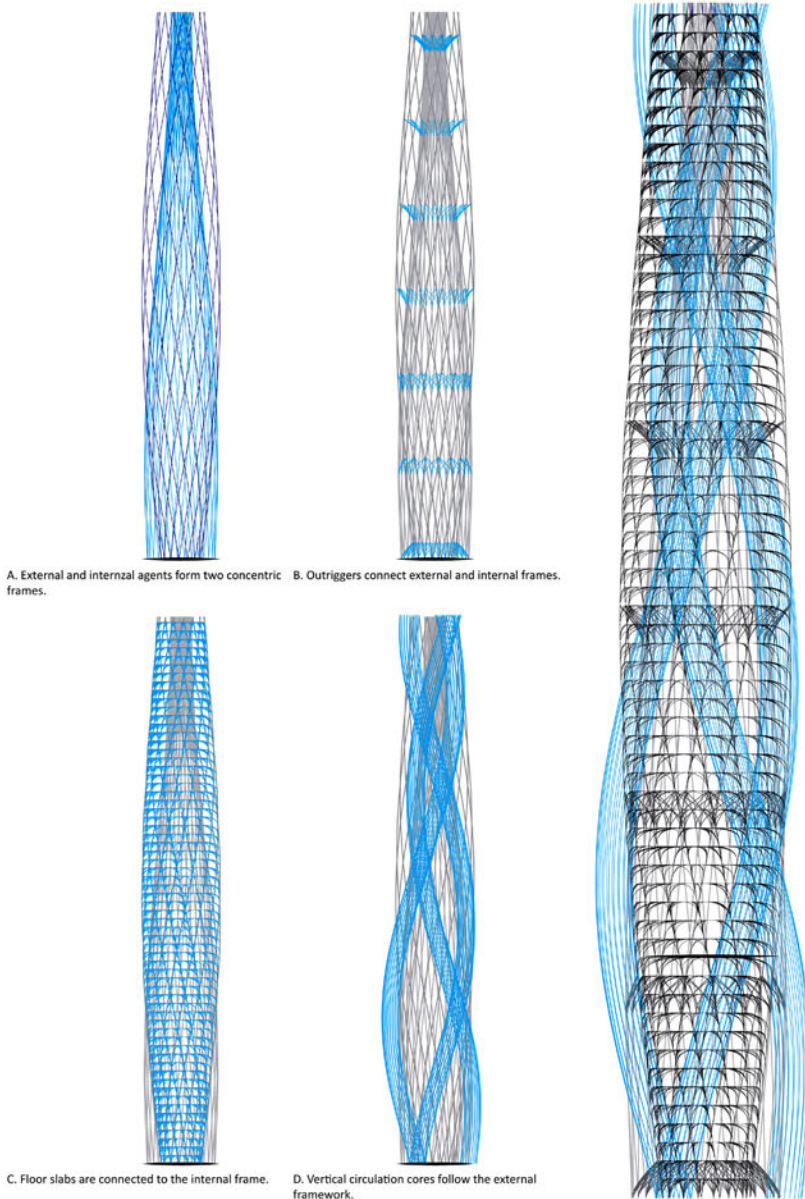


Fig. 8
Exploration showing the investigated subsystems.

As the agent-based system builds up the double structure, vertical circulation, outriggers and floor slabs simultaneously, a bundling algorithm calculates the minimal detours system necessary to concentrate the fibrous paths and thereby optimize the forces travelling throughout the tower. The percentage of bundling can be manipulated according to the individual subsystems, the vertical position of the members, or the location of the members along the circumference of the tower. The minimal de-

tours system has the potential to manipulate the behavior of the members on a local level, creating ways of fine-tuning the structural performance as well as defining various spatial configurations according to transparency levels, orientation, and views, thereby refining the interface between the tower and its contextual environment. As such, form-finding through the minimal detours system can move away from acting as a 'single objective optimization' and progress towards becoming a 'multi-parameter integration' tool due to its coexisting structural and spatial attributes.

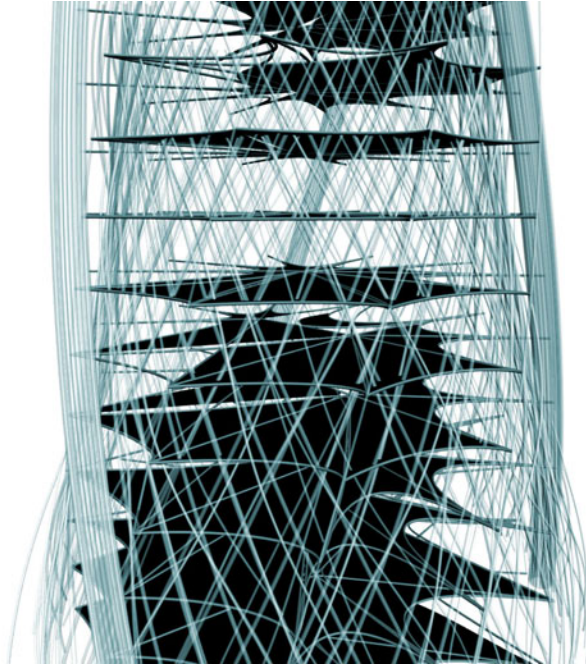


Fig. 9
Bundling algorithm applied to floor slabs.

Conclusion

Currently, geometrical and structural analyses are being applied on the design explorations for the integration of structure, floor slabs, and vertical circulation. Geometrical analysis is performed via the examination of spatial performance in relation to programmatic and circulation parameters. Structural analysis is being carried out via the FEA software Strand 7. The results of the structural analysis will serve as a feedback mechanism in order to refine the positioning and number of floor slab and outrigger elements. After this stage, the second group of subsystems, namely the structure, façade, and environmental systems, will be investigated through the agent-based system by setting up respective parameters for the façade and environmental systems.

In this way, the final integration of the two clusters of subsystems will be achieved by keeping the structural parameters the same for both clusters.

At this stage of the research, it has been observed that the behavior of the various subsystems can be manipulated simultaneously by modifying the parameters which coordinate the local interactions between agents. By using agent-based systems as a computational tool, a hierarchical systematic approach displaying the quality of emergence from lower level organizations, tower subsystems, towards a higher level integrated tower design can be devised. The biological analogous models which are being explored can serve as unique models in the generation of “topological variation” throughout the height and circumference of a singular subsystem. Moreover, these models can also perform to enable the “inter-system differentiation” taking place between multiple systems owing to their inherent geometrical and material organizations.

The research aims to reconfigure all the main elements of contemporary tower design, which in turn will liberate the fixed typology of the tower towards a novel tower system that is described with the qualities of adaptation, integration, and fluidity. Through this research, the major questions that are sought to be answered are: What can we learn from biological processes in order to form an integrated design approach that can create context-specific tower design which operates on multiple levels? Can we devise an evolutionary system for tower design which can continuously adapt to its environment? *“Generative Approaches in Tower Design: Algorithms for the Integration of Tower Subsystems”* aims to bring out new forms of design knowledge in the area of tower research by merging architecture, biology, and computation.

Notes

- 1 Frei Otto, IL 3, *Biology and Building* Part 1, 9.
- 2 In this research, “tower”, “tall building”, and “high-rise” words are used in an exchangeable manner.
- 3 Aiello, Carlo, ed. *Evolvo: Skyscraper for the XXI Century*. USA: Evolo Publishing, 2008.
- 4 Mir M. Ali and Kyoung Sun Moon, “Structural Developments in Tall Buildings: Current Trends and Future Prospects,” *Architectural Science Review*, Vol. 50.3, 205.
- 5 *ibid*, 208.
- 6 Mauro Couceiro, “Architecture and Biological Analogies; Finding a Generative Design Process Based on Biological Rules”, Session 13: Generative Systems – eCAADe 23.
- 7 Michael Weinstock, “Self-Organization and Material Constructions,” *AD Architectural Design: Techniques and Technologies in Morphogenetic Design*, Vol. 76, No. 2 (2006), 35.
- 8 Khosrow, G (2005) Bamboo as Reinforcement in Structural Concrete Elements. *Cement and Concrete Composites* 27, 637-649.
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**From Fields
to Agent-Based Systems**

Fields and agent-based systems

In 1997, Stan Allen, in his influential article "From Object to Field"¹ discusses how architecture moves from an understanding of the object - a figure with clear limits against a background - to the understanding of the field - an assembly of many similar elements distributed in space - with what he names as 'field conditions'. As he writes, "... we might suggest that a field condition would be any formal or spatial matrix capable of unifying diverse elements while respecting the identity of each. [...] The internal regulations of the parts are decisive; overall shape and extends are highly fluid."² Objects are defined by hierarchical relationships where geometrical principles are imposing the relation of the parts to the whole. In their representation, lines clearly define their borders. In fields on the other hand "independent elements are combined additively to form an indeterminate whole"³. The parts are organized in a bottom-up fashion to form the whole. In their representation, lines become variable vectors that connect rather than divide. Allen then goes on to specify the properties of a field: One is *multiplicity*. Fields are always multiple, since they are made out of a large number of individual elements, but most importantly because they allow multiple connections/relations between those elements. Then, they have a *non-hierarchical* character. Each element of the field is equal to all others, and gets differentiated from them due to local conditions. Finally fields are *inherently expandable*: a field can be expanded, virtually to infinity, without changing its inherent rules and syntax. As already mentioned, in that context - that is in moving away from objects towards fields - our understanding of limits change: lines are no longer representing the edges of object - thus dividing - but are instead becoming vectors - thus directing flows, connecting. Consequently the difference between several objects, the seams, tends to disappear.

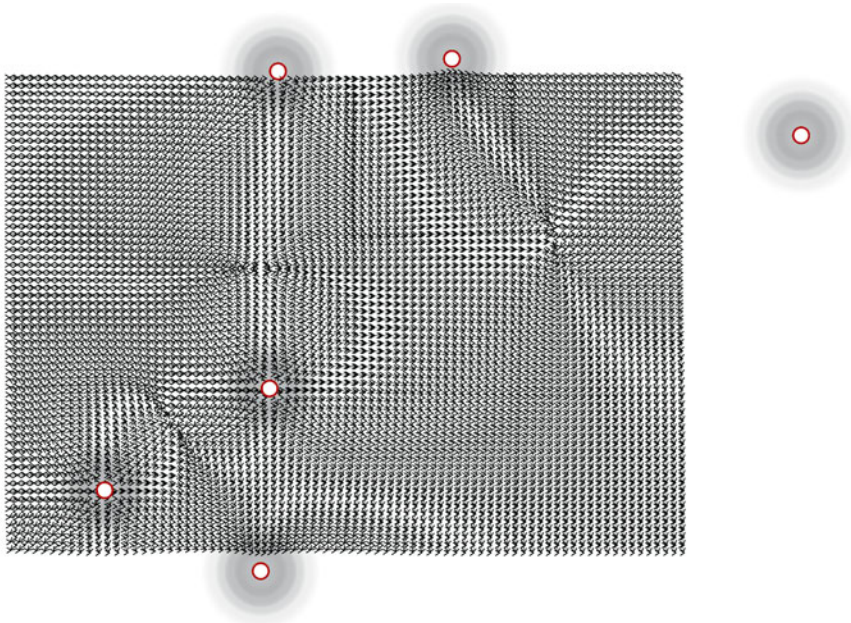


Fig. 1

Folding the suburbs, attractor field.

If we try to abstract or generalize the idea of field conditions, we could deduce that the basic element of a field is in its essence – no matter what its visual representation is – a vector⁴. A vector has – at least in Euclidean space – a length (or magnitude) and a direction. Therefore a field of vectors becomes the ideal tool to represent, to study or to create flows (of energy, of matter, of information). The vector becomes the unit that through its multiplication and local differentiation allows us to shift our focus towards motion, flows and constant fluidity. A second instrument that becomes of value in the study and the representation of fields in conjunction with the vector, is the grid. Since a field is a continuous condition, in most cases without gaps or seams, in order to understand it we need to sample it, i.e. to find its values at specific positions. The intersection points of the lines of a grid become the usual way in which such as sampling is taking place. On top of being a sampling aid, the grid is also emphasizing the lack of hierarchy in the structure. All elements are of equal importance, therefore distributed in equal distances from each other and linked to each other through connections of equal nature.

Stan Allen claims that his article “...parallels a shift in recent technologies from analogue object to digital field”⁵. The idea of the field of course is definitely not something introduced by digital technologies. For example, as early as 1269 Petrus Peregrinus de Maricourt mapped with iron needles a magnetic field. Almost 400 years later, Rene Descartes created one of the first drawings representing a magnetic field (see Fig. 2). The widely used representation of a field through contour lines was invented in 1701 by Edmond Halley. Representation through the contour lines – or isolines – was established since then as a prevailing way to reproduce different conditions from meteorology, where they can represent barometric pressure, temperature or wind, to geography and oceanography, where they represent elevation and depth or, as mentioned before, magnetism. For example in 1726 the engineer Nicholas Cruquius used, for the first time in that context, contour lines to represent the riverbed of Merwede river (see Fig. 3). Representing the curvature of a surface with contour lines, clearly demonstrates an understanding of that surface not so much as an object that can be represented by its borders, but as a field where a given property (here the curvature) is changing along its area. Therefore the notion of the field was available to architects from the beginning of modernity, albeit as a complementary tool. Similarly, already from the 18th century field theory appears both in mathematics and physics.

While the idea of the field as we explained above is predating modernity, throughout its course the field was a concept subordinated to the idea of command and, at least in architecture, occupied a marginal place. Computation then, indeed offered a new perspective towards the notion of the field. The very core of digital processes seems to point towards a field condition, at least as understood by Stan Allen: Whenever an amount of data takes a digital form, independently from how we chose to visualize that information, the encoding process is always a process of creating lists or matrices; large arrays of numerical, homogenous data. In other words the encoded information takes the form of a field or at least the form of a sequence of undifferentiated numerical data where each element is of equal importance. As William Mitchell illustrated while analyzing digital photography⁶, unlike traditional photographs, digital ones are just sequences of numbers, a two dimensional array of integers that can be

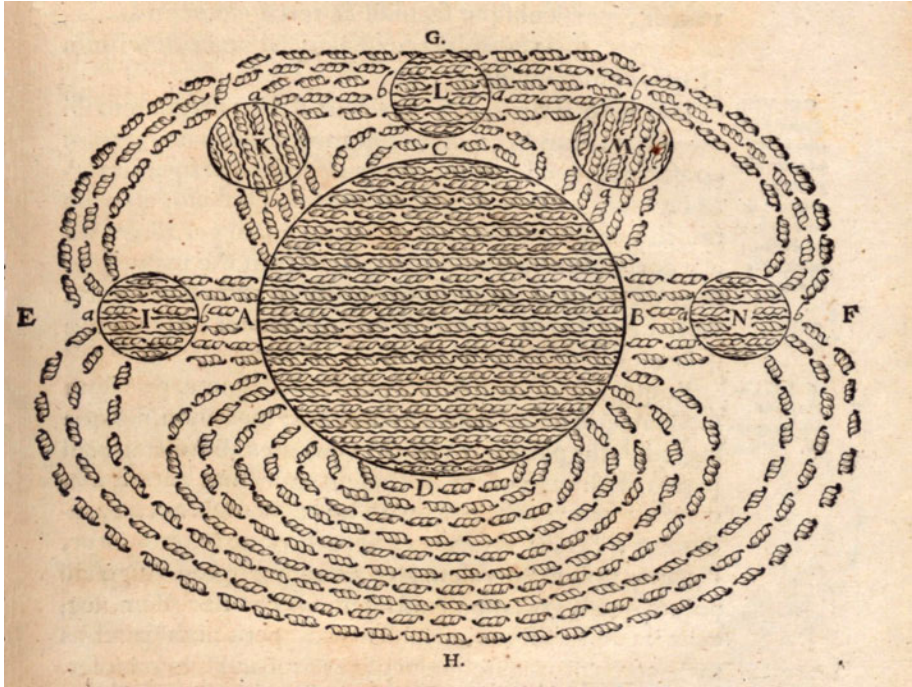


Fig. 2
 Descartes, Drawing of a magnetic field (source: wikipedia).



Fig. 3
 Nicholas Cruquius, map of the river Merwede (source: wikipedia).

transmitted or edited at will, while the digital photograph retains its structure intact. As a result in the encoding of a digital photograph there is no difference between foreground and background for example; everything becomes a grid of pixels where each one is equal to all others. Therefore, all digital means are in a sense governed by a field condition, albeit a serial one. This leads inevitably to a reconsideration of the field and its movement towards the center of our focus. At the same time it is of equal importance the fact that computation, to an extent precisely because of its sequential nature, added the tools necessary in order to study field conditions in much more depth, more efficiently and faster. So while the digital computer did not invent the concept of the field, nor it made it available to architects for the first time, it did help in the change of focus from objects to fields.

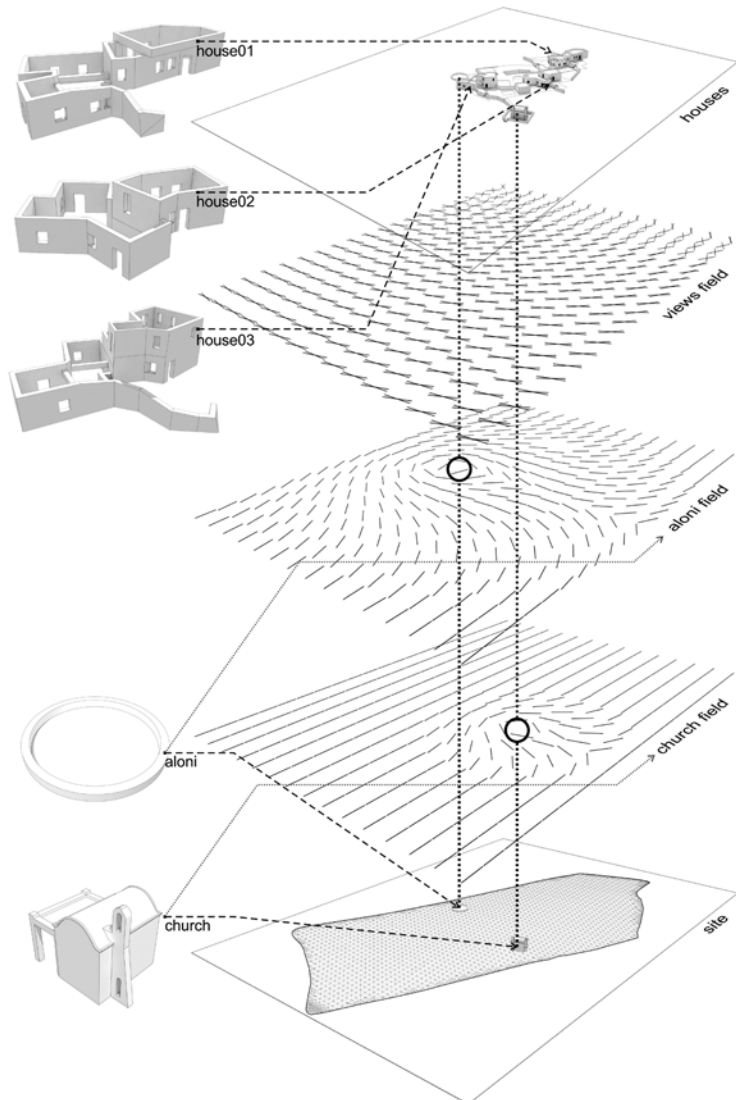


Fig. 4
Object-e architecture, field houses, 2010.

However, as our understanding of computation in the context of architecture is expanding, we become able of imagining - or more correctly transferring into the architectural discourse from other research areas - some more 'advanced' field conditions: A first step for example, would be to add local intelligence to the elements of the field, changing the system into something more dynamic and able to generate by itself novice configurations that emerge out of the simple rules that specify its intelligence. Cellular automata is a good example of that case: A cellular automaton is a discrete model that consists of a normal grid of cell⁷, each one having one out of two possible states: on or off, occupied or not occupied (1,0). The surrounding cells define the neighborhood of the cell. A new generation is created according to a fixed set of rules. The rules specify how many cells in the neighborhood of each cell need to be active in order for the specific cell to become occupied or unoccupied in the next generation. The rules are applied simultaneously to all the cells of the grid. In a certain sense, the characteristics of the field are an intrinsic part of a cellular automaton: it is multiple, non-hierarchical and inherently expandable. The elements - the cells in this example - remain in their fixed positions, the grid, only that now they don't follow a pre-defined pattern or flow, but instead they generate it on the fly, dynamically and intelligently. In other words, what is new in cellular automata is that flow is generated internally, as part of the system itself.

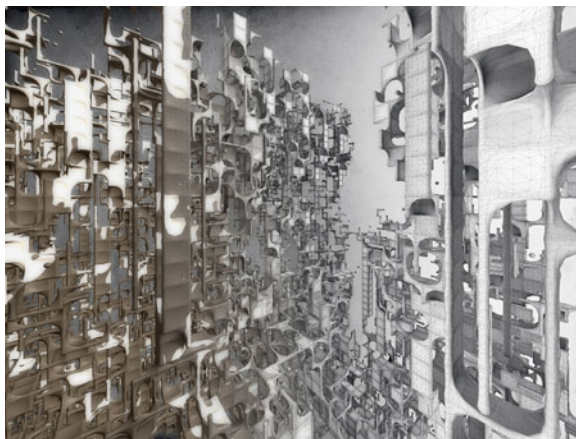


Fig. 5, 6
Object-e architecture, CA landscapes, 2011.

This eventually leads us to the next step: agent based systems; which are an expansion or a generalization of the idea behind cellular automata⁸. An agent-based system is a computational model that simulates the behavior of autonomous agents. This behavior is determined by usually predefined rules that specify how each agent is operating and how it interacts with other agents. A characteristic property of such systems is that they have the possibility to produce highly intelligent behavior which was never directly programmed in the system; such behavior emerges as a result of the interaction of the agents. A well-known example is that of Craig Reynolds' model, developed in 1986 in order to simulate the movement of animal aggregations like flocks of birds and schools of fish. Reynolds' approach was to create a system of agents that are following three very simple rules: separation, where the agents steer to avoid crowding local flockmates, alignment, where the agents steer towards the average heading of local flockmates, and cohesion, where the agents steer to move toward the average position of local flockmates⁹. Through those three simple rules a complex behavior that resembles the movement of flocks or schools emerges.

Stan Allen in his text already discusses flocks, schools, swarms and crowds¹⁰ as a version of what he calls field conditions: *"The flock is clearly a field phenomenon, defined by precise and simple local conditions, and relatively indifferent to overall form and extent"*¹¹. Indeed, following the passage from 'static' fields to cellular automata and then to agent based systems that we traced in this article, the characteristics of the field seem to persist: Agent based models are, similarly to what we noted for cellular automata earlier, multiple, non hierarchical and inherently expandable. Intelligence is still an essential part of the system, as in the case of cellular automata, only that now the elements are transforming into agents. They become able to move independently while still obeying global rules, increasing the amount of complexity in the system. Here, again, the flow and the movement of the system are generated by the system itself and not an external factor.

Concluding with Stan Allen's article, if we try to trace its scope and summarize it, we could argue that the proposed field conditions are conceived by the writer as an alternative, or an antithesis, to what modern architecture, or in fact architecture throughout modernity, established as the *modus operandi* of the architect: *"Field Conditions is opposed to conventional Modernist modes of composition as much as it is to classical rules of composition. My thesis here is that in Modernist composition by fragments – montage strategies that work to make connections between separate elements brought together at the site of composition – the classical assumption that composition is concerned with the arrangement of, and connections among, those parts persists"*¹². Field conditions therefore arise as an 'anti-modern' approach that tries to resist assumptions and principles of modernity in the ways that architecture is understood and produced.

Paul Rudolph's diagrams of the Barcelona pavilion

In 1992, Paul Rudolph created a number of diagrams (see Fig. 7) interpreting Mies Van Der Rohe's Barcelona Pavilion, after a visit to the reconstructed building. Rudolph's diagrams, bypass the form of the pavilion, along with the very strict geometries that define it and instead map the pavilion in terms of reflections, light and shadows, movement and distribution of space. Using color pencils he draws on top of a plan of the

pavilion, utilizing points, vectors and contour lines as the main means of the representation. Commenting on the pavilion and his diagrams in an interview with Peter Blake, he notes: *"This flow of space continues all the way through the building in a highly disciplined way: nothing is left to chance. In my diagram the compressed space, the liberated space, the movement of space diagonally, vertically and curved space modify the rectangular plan in a very clear and surprising fashion. The space is revealed but also hidden. The density of space is greater as it approaches the defining planes that form the pavilion. This inward pull to the defining planes is offset by the reflective surfaces, so that most of the surface vibrate. I have tried to define the essential fluidity of these spaces and the interconnection of the inside and the outside. The highly disciplined flow of space is all-pervasive – a natural constriction and release of space that leads you on, on, on; everything is in motion and you are carried along almost by unseen but felt forces"*¹³.

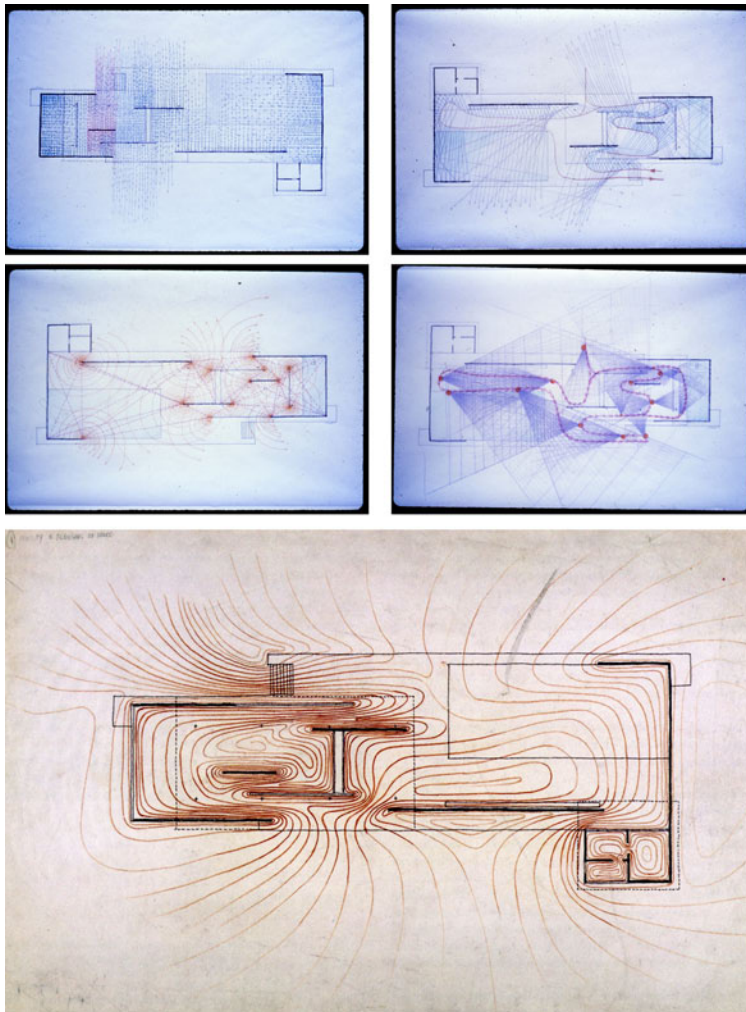


Fig. 7
Paul Rudolph, Barcelona Pavilion Diagrams, 1992.

Both the diagrams and the description come as a surprise. Here we have Paul Rudolph, one of the most celebrated architects of 'brutalism', describing one of the most iconic and fetishized 'object-building' of modern architecture. The Barcelona pavilion is widely considered one of the projects that encapsulate better the principles of the modern movement. With the clearly defined lines, the open plan resulting in a homogeneous space, the lack of ornament, the pavilion stands undeniably as a masterpiece of the architecture of the first half of the 20th century. At the same time Paul Rudolph himself proved to be, through his work, a very dedicated follower of the modern principles, which he developed and applied to his projects. And yet the result is the opposite of what one might have expected. Rudolph draws and talks in *terms of fields*. The pavilion-object gives its place to a variable field of reflections, shadows and moving space. The word 'flow' is used repeatedly; the resulting space is described as a result of "unseen but felt forces". Rudolph himself does not hide his own surprise: "*I expected to see a composition of rectangles and minor and major axes, but it isn't that way at all. It is very fluid and the space moves in ways that are difficult to imagine.*"¹⁴ So what does it mean this reading of the Barcelona pavilion? Did Paul Rudolph change direction toward the end of his career or did Mies design the pavilion using field conditions as his tool? As the rest of the aforementioned interview proves there is no base to support the former, and of course there is no available information confirming the later. Then a third explanation might be possible: the two - the predominant understanding of the Barcelona pavilion as an iconic modern building and Paul Rudolph's interpretation of the pavilion as a field - might coexist and relate to one another.

Altermodernity

"There has also been present an alternative path that poses the possibility of breaking definitely with the relation of command that modernity invented."

Antonio Negri and Michael Hardt, Commonwealth

Antonio Negri and Michael Hardt in the third installment of their Empire trilogy, Commonwealth, are trying to trace throughout the course of modernity instances of resistance to modernity itself. They call these moments of opposition and rapture with the principles of modernity, antimodernity. They utilize a large array of examples to illustrate their point: from the Zapatistas movement in Mexico, to the existence of monsters as a common theme in colonial literature. They claim however that the constituting principle of modernity is above those usually mentioned – enlightenment, the break with tradition, secularism etc – a power relation between modernity and antimodernity¹⁵: "*Modernity is always two. [...] a power relationship: domination and resistance, sovereignty and struggles for liberation*"¹⁶. That means that antimodernity as defined by Negri and Hardt is not something external to modernity or a simple continuation of pre-modern practices: "*Forces of antimodernity [...] are not outside modernity but rather entirely internal to it.*"¹⁷ So antimodernity they claim is neither an "*attempt to preserve the premodern or unmodern from the expanding forces of modernity*"¹⁸, thus it is not an attachment to tradition, neither something external or independent to modernity. Instead modernity and antimodernity are closely related to one another, the later defining moments of resistance to the former. Only that the oppositions is not

of a dialectical nature; instead the two are connected in diagonal manner, are interwoven to each other and each totally dependent upon the other. Modernity cannot exist without antimodernity and vice versa.

Following the juxtaposition of antimodernity to modernity, Negri and Hardt claim that antimodernity has the possibility to be transformed into what they call *altermodernity*: *“Altermodernity has a diagonal relationship with modernity. It marks conflict with modernity’s hierarchies as much as does antimodernity but orients the forces of resistance more clearly toward an autonomous terrain.”*¹⁹ So altermodernity moves from resistance to alternative, it *“breaks free of the power relations of modernity”*²⁰ and of any dialectic bounds and *“emerges as a dynamic, creative process”*²¹. Altermodernity, while rooted in antimodernity, is a condition that no longer needs modernity in order to exist; its creative power comes from within its own principles. That creative power is what the writers have already described as the multitude²²: a highly distributed and networked formation of singularities that are able through their distributed nature to self-organize towards a state of autonomy.

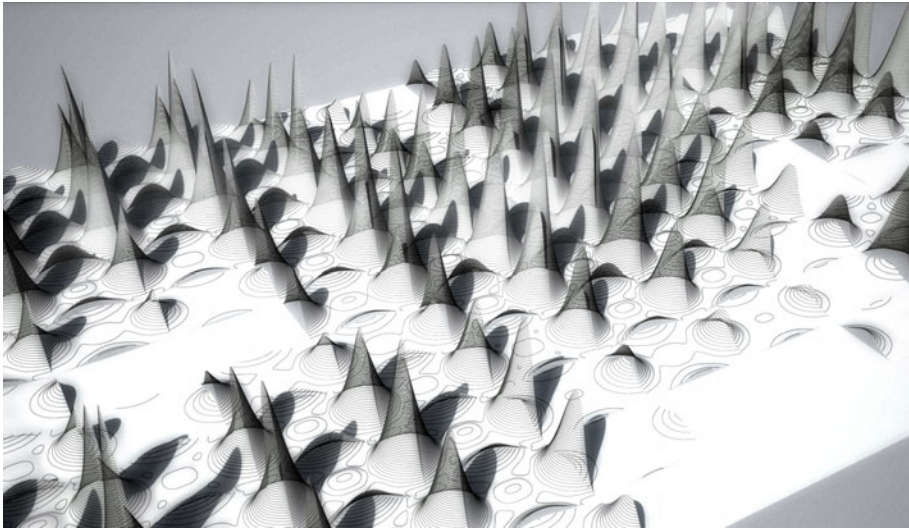


Fig. 8

Object-e architecture: morpher field, 2011.

From fields to agent-based systems

Transferring concepts from philosophy and the political sciences to architecture is always risky, however, having in mind the above is tempting not to relate Stan Allen's Field Conditions with the concept of antimodernity. As already discussed, field conditions are proposed as an opposition to conventional Modernist²³ and classical modes of composition, and therefore as an opposition to the manifestations of modernity in architecture, the idea of the command that directs the hierarchical relationships of parts to whole. And as the example of Paul Rudolph's diagrams of the Barcelona

Pavilion clearly demonstrates, field conditions, in their opposition to the expressions of modernity in architecture can be directly related to them. The two concepts are dependent to each other, the later needs the former in order to exist and vice versa. So much so, that the difference between the two can be just a change of the point of view. Paradoxically, as Negri and Hardt point out for the relation of modernity to antimodernity, the fields are actually pre-existing modernity in architecture; they are not a result of a reaction to it: *"We should not think of power as primary and resistance a reaction to it; instead [...] resistance is prior to power. Here we can appreciate the full im-*

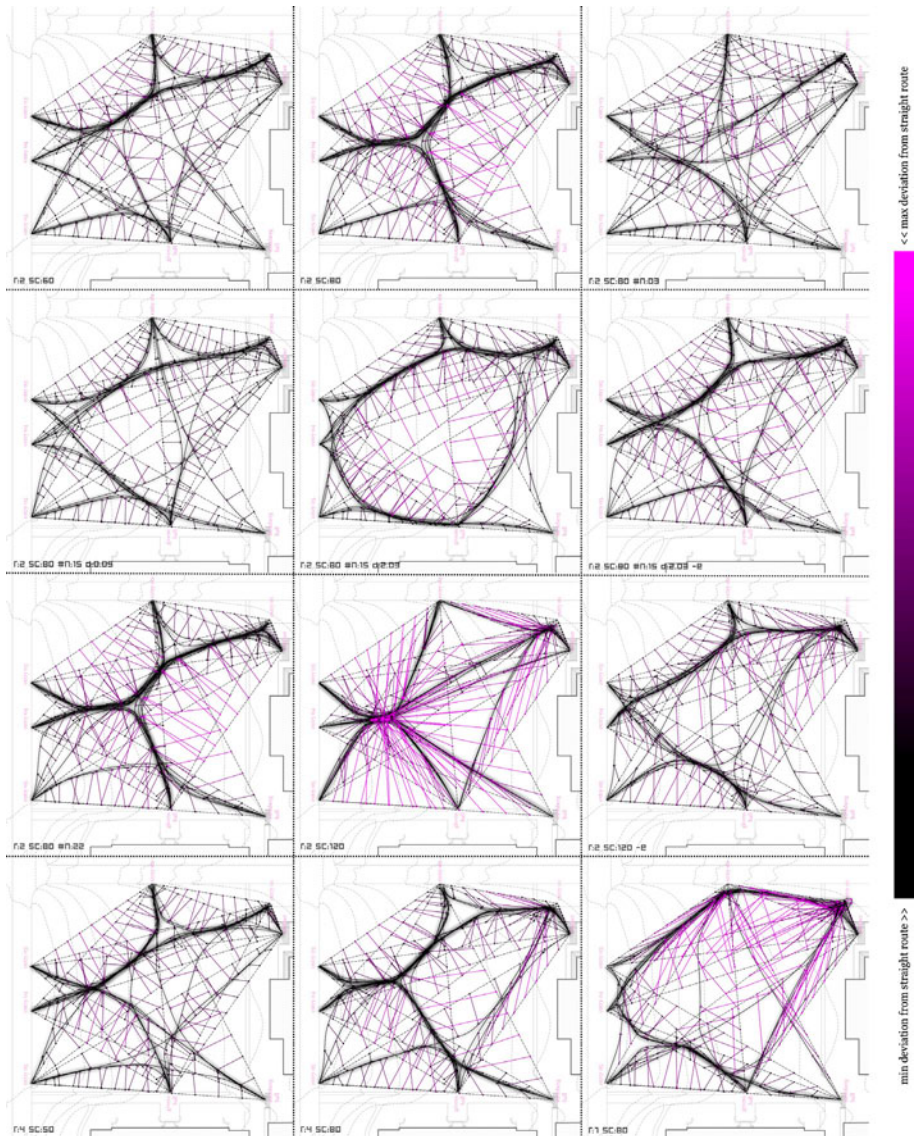


Fig. 9
Object-e architecture: Hybrid*, movement displacement fields, 2012.

portance of Foucault's claim that power is exercised only over free subjects. Their freedom is prior to the exercise of power, and their resistance is simply effort to further, expand and strengthen that freedom"²⁴. As in the case of the Cordoba Mosque, the main architectural example used by Allen in order to illustrate what a field condition is: The field, the first part of the Mosque, is pre-existent and its properties can be seen as resistance towards what comes to be added to it. Resistance that succeeds by transferring the properties of the field to all the extensions added to it: "*Significantly with each addition, the fabric of the original remained substantially intact. The typological structure was reiterated on a larger scale, while the local relationships remained fixed.*"²⁵

If we parallel field conditions with antimodernity however, a obvious question arise: How can the fields be transformed from an opposition to modernity, to a new creative process released from its bounds and the duality of modernity – antimodernity? How can field conditions be transformed into a form of altermodernity? Let us then reconsider the relation of agent based systems to field conditions. As we concluded earlier they do share some common characteristics which are precisely those properties that according to Allen are displayed by fields; namely, they are multiple, non-hierarchical and inherently expandable. At the same time however, agent based systems, presented by Allen as one of the cases of field conditions, possess some characteristics that are fundamentally different from all the other cases.

The first is the origin of the 'moving force' of the system. In agent-based models it is internal to the system itself. Swarm models are dynamic and in constant motion because of the simple rules that are embedded in the same model and therefore they do not require an external force to set them in motion; they are characterized by a certain level of autonomy. As Negri and Hardt write for the multitude, the driving force of altermodernity: "*[t]he vision of the multitude [is] composed of a set of singularities and based on practices of self-determination, [...] the common [...] [and] its constant metamorphosis, its mixture and movement*"²⁶. That property of self-determination, inherent to agent-based models seems to evade Allen: Writing about post-minimal art as an example that operates on the basis of field conditions he notes about the artist Barry Le Va: "...*he began making pieces [...] that thoroughly dissolve the idea of sculpture as a delimited entity [...] As with other examples described above, local relationships are more important than the overall form. The generation of form through 'sequences of events' is somewhat related to the generative rules for flock behavior...*"²⁷. What he fails to see then, is that the relation of Barry Le Va's creation to models of flocks is only similar to the relation of analog photograph to digital as described by William Mitchell: The result, or the printed image might look the same, but the principles behind each process are fundamentally different: Le Va's works are defined by an external force imposed by him during the whole process of the creation of the 'sculpture' while flock behavior is set in motion by internal forces and therefore is self-organized. At the same time Le Va's 'sequences of events' are obviously sequential, serial, while the generative rules of flocking models are operating always in *parallel*.

This brings us to the second important difference: the opposition of seriality to parallel processes. That difference also escapes Allen's article: while he initially notes that a shift from object to field "*pays close attention to [...] [p]ost-war composers as they move*

away from the strictures of serialism, employed concepts such as the cloud of sound..." He then moves on to 'Digital Fields' where he writes, quoting Vivian Sobchal: "Digital electronic technology atomizes and abstractly schematizes the analog quality of the photographic and cinematic into discrete pixels and bits of information that are transmitted serially..."²⁸ and further down: "The universal Turing machine – the conceptual base of the modern digital computer – performs complicated relational functions by means of serially repeated operations of addition"²⁹. The juxtaposition of seriality to parallel processes however is a fundamental one. As a matter of fact, contemporary digital computers, exactly because they are operating serially, they are unable to precisely simulate agent based models like flocks and swarms. All agents in such models need to operate in parallel; each new step of the simulation is discrete from the previous and every new position or state of the agent depends on the state of the other agents in the previous step; all agents need to be updated simultaneously in every step. Modern computers then, being unable to operate in parallel to the extent that would require a simulation of hundreds of agents, are faking the parallel process: they calculate each agent after the other serially and after that calculation is finished they update each agent again one after the other serially. The parallel, distributed nature of agent-based systems then, is simulated in modern computers by a reference to a central memory, that stores the already calculated results until all are calculated and can be applied; it operates through clearly defines hierarchical relations. The difference might appear minor, since the result is visually the same, however it is not; As Francisco Varela has already shown in 1979³⁰ it actually underlines the whole history of the development of

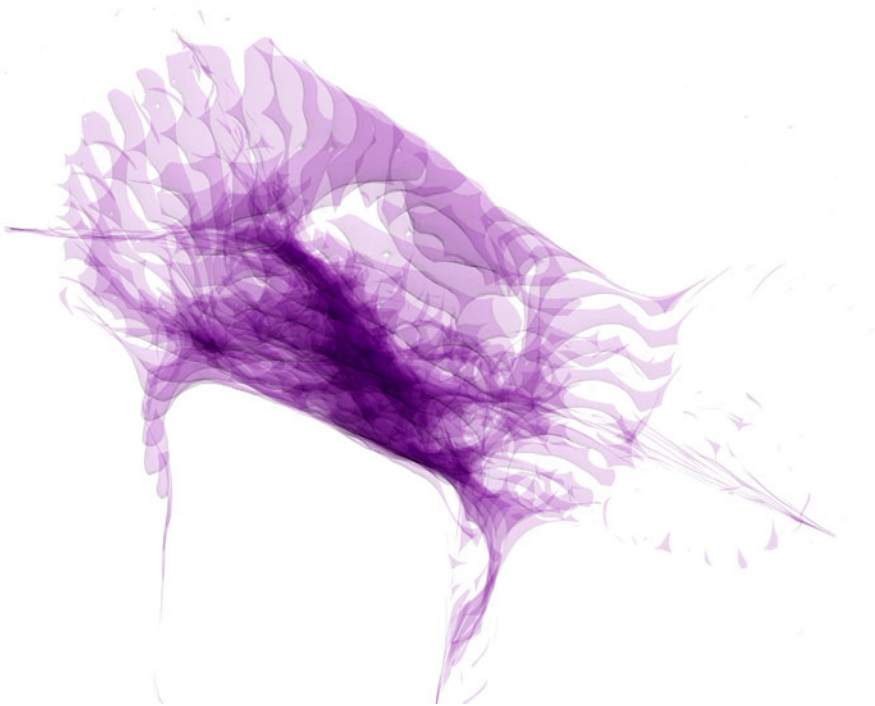


Fig. 10
Object-e architecture: Green square library crowd studies, movement agents, 2012.

the digital computer going all the way back to its beginning. There we find two ideas that confront on another. The first was developed by von Neumann (who thought of the computer as a universal machine): it is the idea of the command, the idea of the black box, a conception of the computer as an instrument that operates serially. The second was developed by Norbert Wiener, the founder of cybernetics, who believed in the idea of autonomy and was therefore favoring parallel processes and calculations. The concept of the "command" is directly related to modernity, while the idea of "autonomy" is concerned with a system and its "*generation, the affirmation of its own identity, [its] internal regulation, [its] internal definition*"³¹. Negri and Hardt are also commending in the importance of parallelism: "*Multitude is thus a concept of applied parallelism, able to grasp the specificity of altermodern struggles, which are characterized by relations of autonomy, equality, and interdependence among vast multiplicities of singularities*"³².

Autonomy and parallelism

Two properties then seem to emerge from the condition of agent based systems as described above: *Autonomy* and *parallelism*. Those two appear to be offering the directions that architects can follow in order to develop an alternative approach to the design and production of spatial conditions; one that breaks free from the tradition of modernity, the idea of command and the burden of dialectics. Their direct origin from the idea of fields is of equal importance: First because they carry on many of their properties and processes. But also because that lineage helps us understand and illustrate that an alternative approach does not have to be the result of rapture; it does not have to be developed as a negation, a dialectical opposition (a paradigm shift), but rather as an affirmation, an intensification, a change of the point of view.

The current endeavor of architecture with agent based systems as the means to explore new morphologies, organizational strategies and material formations is a first step in that direction. As such it might soon prove to be a superficial one; albeit necessary. The distributed nature that our society is rapidly assuming is already having profound impact in many different levels of modern life, therefore architects cannot expect that it will affect architecture only at the level of the design processes that they employ; it is quite possible that it will alter the very nature of architecture itself. But that remains to be seen.

Notes

- 1 Stan Allen, "From Object to Field," *AD (Architectural Design)* 67, no. 5–6 (February 11, 1998): 24–31.
- 2 *Ibid.*, 24.
- 3 *Ibid.*, 25.
- 4 In mathematics, physics and engineering, a more general term is the 'tensor'. Both vectors and scalars are subcategories of tensors, which was established as an idea in order to represent more complex conditions.
- 5 Allen, "From Object to Field," 24.

- 6 see William J. Mitchell, *The Reconfigured Eye: Visual Truth in the Post-Photographic Era* (MIT Press, 1992).
- 7 The grid of a cellular automaton can be of any dimensions. However, the most common examples studied are one-dimensional and two-dimensional cellular automata.
- 8 A cellular automaton can be considered itself an agent based system, where the cells are the agents.
- 9 Craig Reynolds, "Boids (Flocks, Herds, and Schools: a Distributed Behavioral Model)," [Http://www.red3d.com](http://www.red3d.com), n.d., <http://www.red3d.com/cwr/boids/>.
- 10 In fact, if we try to be more accurate, we don't really know if flocks of birds, schools of fishes etc are actually functioning as agent based systems. Agent based models are able to reproduce the movement of such formations, but the processes used for that reproduction are a 'human invention' and not a replication of the way that birds or fishes are actually getting organized.
- 11 Allen, "From Object to Field," 26.
- 12 Ibid., 27.
- 13 Roberto de Alba, *Paul Rudolph: The Late Work* (Princeton Architectural Press, 2003), 213.
- 14 Ibid., 215.
- 15 on the duality of modernity see Michael Hardt and Antonio Negri, *Empire* (Harvard University Press, 2001).
- 16 Michael Hardt and Antonio Negri, *Commonwealth* (Harvard University Press, 2011), 67.
- 17 Ibid.
- 18 Ibid., 101.
- 19 Ibid., 102.
- 20 Ibid.
- 21 Ibid., 104.
- 22 The multitude is a term coined by Machiavelli and then developed further by Hobbes and Spinoza. Hardt and Negri develop their own understanding of the concept starting from Spinoza's writing. For an understanding of the concept see Michael Hardt and Antonio Negri, *Multitude: War and Democracy in the Age of Empire* (New York: Penguin Books, 2005); and Antonio Negri, *Savage Anomaly: The Power of Spinoza's Metaphysics and Politics* (U of Minnesota Press, 1999).
- 23 Modernity must not be confused with modernism, or in our case with modern architecture. However, modern architecture is an expression – and possibly the ultimate one – of modernity in architecture. Therefore an opposition to modernism in architecture can be understood as an opposition to the principles of modernity as they are solidified in architecture. At any case, Stan Allen is extending that opposition to "classical rules of composition" therefore he extends the juxtaposition so as to cover most of the architectural 'incarnations' of modernity.
- 24 Hardt and Negri, *Commonwealth*, 81.
- 25 Allen, "From Object to Field," 25.
- 26 Hardt and Negri, *Commonwealth*, 112.
- 27 Allen, "From Object to Field," 26.
- 28 Ibid., 28.
- 29 Ibid., 29.
- 30 see Francisco J. Varela, *Principles of Biological Autonomy* (North Holland, 1979).
- 31 Ibid.
- 32 Hardt and Negri, *Commonwealth*, 111.

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Digital Materiality:
Conception, Fabrication, Perception
New issues for educational programs

Introduction

New technology is dramatically changing our approach to design. The digital dimension affects the way designers work within the new mode of discerning, conceiving and imagining space. The use of computers in the architectural field started early during the sixties with the work of Negro Ponte (Negro Ponte, 1970)¹, and later with famous players such as Alexander (Alexander, 1974)², John Frazer (Frazer, 1995)³, Paul Coates (Coates, 2010)⁴ and Kostas Terzidis (Terzidis, 2006)⁵. More recently we can mark the increasing development of parametric modelling and digital fabrication; generative modelling and exploration processes; hybridization of digital and analogical tool all in used in order to assist the designer at each phase of the architectural conception. The expansion of scripting and the new characteristics of creativity in the informational age have both paved the way of algorithmic design and modelling.

This new paradigm is transforming the architectural practices and three main features could be defined. The digital thinking, the digital manufacturing and the digital perception are representing three conceptual levels that reveal new modalities of conception, of fabrication and perception. Starting with the theoretical definition of these notions, we will provide illustrations of works achieved during our educational or research programs. Revealing new knowledge and new skills these examples could be used to define new educational objectives, methods and issues.

Digital thinking

Form in a continuum

During the eighty, Gilles Deleuze (Deleuze, 1988)⁶ introduced the notion of “objectile”, in order to characterize a new paradigm following the transformation of our industrial production methods. Objects are no longer associated with a standard and a mass production but more with a fluctuation and a continual variation. Digital machines are replacing the stamping methods. The form is inscribed inside a continual series of potentialities; the final shape is a singularity, an occurrence or an event among a larger and infinite sequence. Starting from here the development of the mass customization is possible.

Gregg Lynn (Lynn, 2004)⁷ abounded in this direction with the concept of BLOB (Binary Large Object). Here the form is animated, modified and transformed by external forces; the deformations are smoothed and continuous. These forces could be invisible and represent the context of the project. Complexity, non-linearity and emergence become the characteristics and the properties of the projects.

To other contemporary architects the form is considered as a whole indivisible, they refer to the “searching shape” (Lucan, 2003)⁸. The morphogenetic principle is based on the use of transformation operators. The architectural form depends of the site limits, and then following external constraints like activities cohabitation or environmental conditions, could suffer pressure and thus could be deformed. The final shape is informed by context, by external and invisible forces. Architects could implement atmospheric morphogenesis logic of conception. Sensible parameters and performance

criteria become parameters and variable those drive algorithmic processes. From logic of modularity, which characterise the modern movement, we shift to logic of individualized seriality, which characterise the digital society (Rocker, 2008)⁹. Each project hypothesis is unique and yet also part of a series. The activity of conception becomes a meta-activity and the architect has to define the condition of emergence and the shape at its limits. More than unique solution, the architect designs a family or a population of solutions (Marin, 2010)¹⁰.

Fig. 1 shows a population of solutions generated with the help of an evolutionary algorithm. In this example the environmental parameters are used to drive the evolution. Here the architect designs a process of emergence; he defines the conditions of performances and he describes the shape behaviour. He doesn't work on a single solution but more on a population of possible solutions.

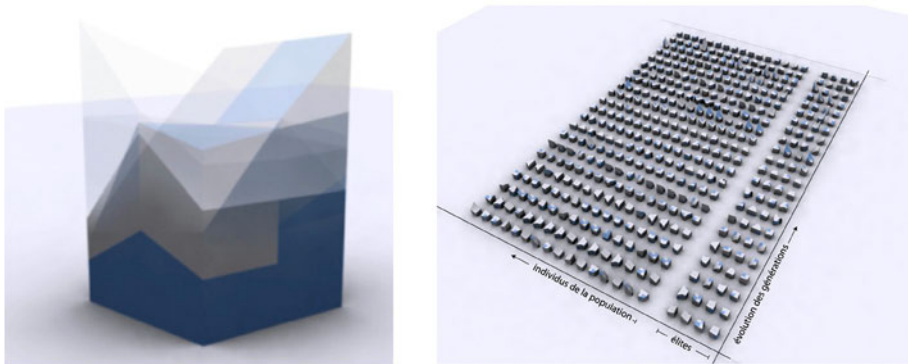


Fig.1
Illustration of a trans-form as a meta-form.

Digital creativity

These attitudes reformulate the processes of creation, which become less subjective, less arbitrary, no longer based on an artistic, individual or divine inspiration. The characteristics of creativity have changed in the informational age (Sevaldson, 2005)¹¹. The individuals are connected; the modalities of cooperation allow the practice of open source developments, the re-using of code or tools, the sampling, the mixing of disciplinary. For Asut (Asut, 2008)¹², creativity has to be collective, architects are one node of a net of people with common interests, which collaborate, share information and generate solutions, the notion of authorship is transformed.

Digital modelling

Thanks to advanced digital tools, parametric modelling allows the construction of a digital model that could evolve with the help of evolutionary methods (i.e. genetic algorithm) or other optimization algorithms. In this context biology and natural processes are convoked in the architectural conception, and natural growth mechanisms or natural selection processes are implemented and interpreted to drive an archi-

tectural design and to help the designer to explore and formulate a solutions space. These methods find their roots in the cybernetic discipline and the complexity science (Morin, 2000)¹³. The complexity articulates uncertainty and organisation inside loops of feedback. It allows the description and the understanding of chaotic systems and gives autonomy to the machine. The notion of information is crucial it becomes an organisation force inside the system. The hazard plays an important role and becomes a structuring mechanism allowing emergence and self-organisation (Atlan, 1986)¹⁴. Based on this, bio mimetic processes are implemented and can simulate proprieties emergence and building self-organisation. The building is considered as a system in interaction.

The logics of digital processes have begun to re-organize the design methods. For Scott Marble (Marble, 2010)¹⁵ three main aspects should be considered. The first is “designing design” which addresses how design processes being influenced by digital workflow. The process of architectural design is integrated in a complex workflow in which geometric and parametric modelling is combined with simulation, analysis and optimization software could lead to the fabrication and manufacturing files generation. The second aspect is “designing assembly” or a material issue, and considers the way material properties and digital fabrication processes take shape in the design concepts. The final aspect is, “designing industry” which is concerned with the timing and sequencing of construction with the help of building information modelling and information management. In this context new industry sectors could be incorporated in the building construction.

Digital manufacturing

Fabrication-conception continuum

The fabrication-conception continuum is broadly associated with the design process tooling, involving a continual trajectory from the conceptual research phases to the prototyping through the mock up materialisation and up to the final product building. This informational continuum (Kolarevic, 2008)¹⁶ paves the way of the mass customisation, the shape is thought as a potentiality, a singularity which takes place inside a larger sequence. At the same time, these practices have opened the way to parametric, algorithmic and generative design. The digital fabricating machines have allowed the constructability of these complex geometries (Iwamoto, 2009)¹⁷. The generative fabrication (Cardoso, 2008)¹⁸ symbolizes these resolves and materialisations concerns.

Fig. 2 shows a series of 3D printing mocks up. The 3D printing technology is used for complex geometries materialization. The results are useful for exploring the qualities of these geometries; the architect searches for singularities and these models take place inside the conception iterative loop based on multiple and varied representations.



Fig. 2.
3D printing mock ups.

Thanks to these digital fabrication technologies and advanced computing, a go and return system between bits and atoms are allowed; new representations have emerged with, for example the use of simulation, 3D printing, CNC cutting and robotic manufacturing. The status of the model has changed; these tools are blurring the boundaries between the make-up of an item and the thing itself. The works of the architects, engineers and constructors are redefined. The characteristics of the fabrication, of the materials and of the construction are embedded in the design of the architect and convoked early during the design process. Technologies allow the realization of complex geometries; the designers are limited by the properties of the materials rather than by the difficulty of describing the designs. New methods of manufacturing are used with, for example the use of robotic allowing non-standard construction and pre-fabricated building elements (Bonwetsch, Gramazio, & Kohler, 2007)¹⁹.

Fig. 3 shows a tessellated wall designed with the help of dynamic simulation. The animation software is used for defining the final shape. The non-standard geometry induced is fabricated with a CNC machine and the one to one scale prototype allows a review and a critical understanding of the shape.

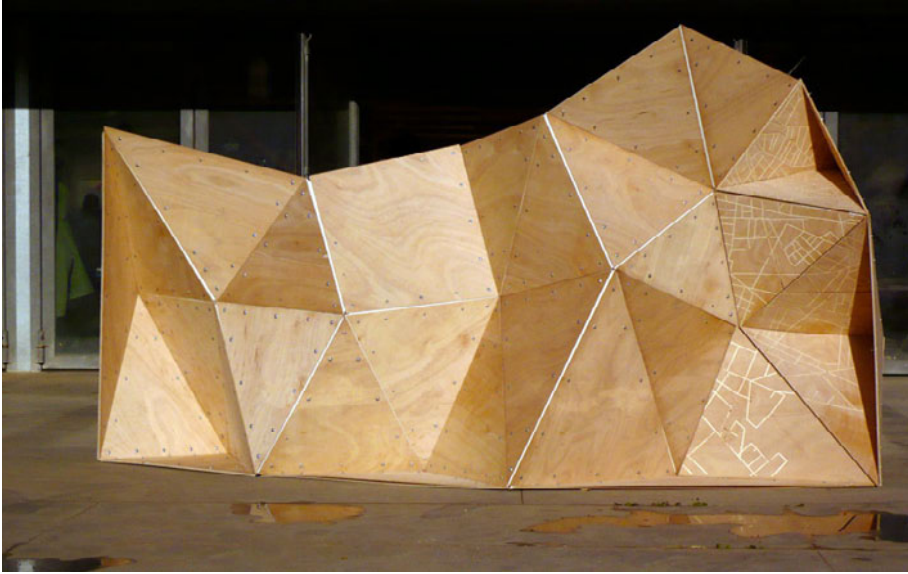


Fig. 3
Tessellated wall, one to one scale prototype.

Smart materials

The use of smart materials represents an other aspect of the architectural field transformation. It takes root in the materials science and it expands the generalization of the matter to questions and appreciates the specificity of elementary bricks customized for individual purposes. The term smart material refers to a new generation of products likely able to perform various functions until now reserved for the living. Usually intelligence is brought from the exterior and acts as a support (Meagher, Van der Maas, Abegg, & Huang, 2009)²⁰. Other experiments try to operate with the inner properties of the material and focus on the link between matter and information (Menges, 2010)²¹. Thus and following Manzini (Manzini, 1989)²², we see a technologisation of materials, which allows designers to define the material properties, rather than simply working from existing qualities. Properties could be integrated at each scale – nano-, micro- and macro-scales - and they could modify structural, chemical and magnetic behaviour, even traditional material could become dynamic. Klooster (Klooster, Boeing, Davis, & Seeger, 2009)²³ provides a state of the art of smart materials applications in the field of architecture and design. The surface becomes the ideal place to negotiate technological, artistic, ecological and social interactions. These intelligent surfaces, thanks to their augmented properties, are an opportunity to enhance social and symbolic meaning.

Fig. 4 shows a smart concrete panel. Capacitive captors, LEDs and electronic cards are included inside the panel of concrete. An interaction is possible and the physical proximity activates a luminous scenario. The passive concrete becomes interactive and sensible to human behaviours.



Fig. 4
Smart Concrete panel (in collaboration with CEA).

Digital perception

From decorum to ornament

More recently we note the increasing interest in the surface treatment and the emergence of what is called a new ornament. This ornament acceptance is dramatically different from the common meaning. The sculptural and symbolic dimensions of the Renaissance concept of decorum, which aimed to articulate the building's cultural and social context, are replaced by a thought on the surface, where patterns are repeated, emergent and digitally generated. Quite different from the tectonic role of the structure in the words of Gottfried Semper, and on the contrast of Adolf Loos position in which he declared ornamentation a "crime". The past decade has revealed a re-interpretation of ornamentation. The works of Herzog and De Meuron architects or Foreign Office Architects are symptomatic of these practices and the literature is flourishing on this subject.

Kolarevic (Kolarevic & Klinger, 2008)²⁴ made some distinctions about different kinds of ornaments in architecture. Ornamentation could be decorative, functional and mimetic. Decorative ornament relies on its application to an already existing surface and could emphasised the specific qualities of an object. The ornament is considered as functional when it is integrated to the building, thus particular treatment of the structure could be part of this category; ornament is mimetic when the symbolic and expressive dimension characterized the device.

Moussavi (Moussavi & Kubo, 2006)²⁵ as well, helps us to understand this renewal of interests for ornamentation. The growing number of large building types that are "blank", department stores, shopping mall, cineplexes and museums, transforms the relationship between inside and outside; in addition, the necessity of flexibility in the architectural programs, both compel the architects to work on the external shell and

to leave the internal definition to other designers. The envelope becomes the support of an architectural manifestation. The architects must give the building an expression that is independent from the inside yet participates to the urban structure. The environmental constraints and the energetic performances requirements of the building induce likewise a sharp definition of the building skin. This focuses the interest of architects.

Fig. 5 shows a bio-inspired building skin. The skin is designed for preserving the privacy of the residents while allowing for sun protection and solar gains. The building reveals a symbolic meaning and participates to the urban structuring.



Fig. 5
Bio-inspired building skin (in collaboration with GTB Architects).

Affect and effect

Moreover the affect becomes one of the major issues of architectural design. The sensation is often conveyed by the surface, and digital architecture plays a central role in the conception and construction of these spaces filled of affect. Following Bressani (Bressani, 2010)²⁶, the affect is immersive and is produced through a constant interaction between subject and object. Subject and object inform themselves mutually, architecture become active and performative. There is no longer a distinction between object and subject but more a sensitive immersion; the space participates in a sensitive experience in which the body is involved. Matter is embedded into virtual realities

and smart components, space is no longer stable, autonomous and homogeneous, but becomes interactive, tactile, interface between our internal body, external experiences and distant communication. As in the experiment of dynamic ornament proposed by Maegher (Meagher et al., 2009)²⁷, data played an important aesthetic and cultural role in the design of architectural spaces, and could help occupants in the task of making sense of their environment. But the effect is also cultural; it depends on our education and cultural environment, our perception is inseparable of knowledge. Citing Baxandall (Baxandall, 2000)²⁸ it is imperative to “live in a culture, grow and learn how to survive in it, is to make a specific perceptive training”.

The multicultural and the cosmopolitan society involve new symbolic communication and consensual icons that could be found in the technological culture. Thus the ornament represents the invisible forces of the culture, in order to create a collective meaning. The mixed, the continuity, the folds, the curves, the loops represent some imagination of creation based on an interactive and informational time and space (Buci-Glucksmann, 2008)²⁹. Thus the digital fabrication allows new possibilities based on non-uniformity and non-monotony through the use of surfaces texturing and variable patterns.

Fig. 6 shows a one to one scale prototype that reveals an immersive and sensible environment in which the visitor is wrapped. The curves and the scrolls of the shape made by addition of multiple sections refer to interiority and propose new forms of spatiality.



Fig. 6
One to one prototype.

New perceptive entities

Tools can be seen as an extension of the human mind involved in our mental activity such as thinking, imagining and interpreting. Computers are considered as an expressive medium, rather than just a tool in a workflow, they influence a designer's thinking through the visual elements produced and generated in order to represent a meaning not only for expressing the designer's idea to someone else but also for the designer within the complex feedbacks and interplays iterative loops of the design process. Architects work by manipulating these visual entities sometimes generated by algorithm within an autonomous process of the machine. In order to expand the limit of the human imagination, in order to help the exploration of the solutions space, a designer has to go beyond the software and has to get skills and knowledge in programming, writing code and algorithms, he or she has to be familiar with computer science, cognitive science and artificial intelligence (Asut, 2008)³⁰.

Moreover the technologic environment in which we live takes part in the manner we perceive the world. For example, automobiles have dramatically transformed our perception of the speed; we are all familiar with the high-speed displacement and their sensitive body experiences. In the same way, computers, information technologies, immersive environments and ubiquitous technologies are progressively enhancing our common sensations and reflexes. New perceptual entities are emerging from the technological evolutions. In this context, the static architectural forms are replaced by dynamic flow, emergent patterns or computed geometries.

Ambient intelligence

The use of augmented space consolidates these realities hybridizations and digital technologies become vector of our interaction and sensations. The delimitation of the space by its physical limits is transformed and enhanced by its interlock with the virtual space. Some virtual layers of information stake the territory and keep inaccessible without digital instrumentation. The communication space and the creation of community or social relationships fall as well, and sometimes simultaneously, in both physical and digital dimensions. Materials are now able to interact with the external conditions, interactive architecture (Fox & Kemp, 2009)³¹ or the efforts for representing the informational flow, attempt to consider architecture as interface between physical and virtual realities.

Frechin (Frechin, 2008)³² proposes the notion of "neo-object" in order to characterize these objects that integrate the notions of situation, services, information and relationships. Passive objects give way to systems, communicating devices, relational objects and interface objects. They represent conjunctions of situations, interaction and representation, exploring new forms of materiality, new temporalities and new situations.

Fig. 7 illustrates the exhibition *Jeux de Paysages* that proposed a representation of the invisible layers of information that are covering the territory. Optical interactions with the physical devices allow the consultation of multiple representations of the territory. These representations could be completed by online uploads while a physical presence on the territory authorizes the consultation of these territory interpretations. A collective space of signification is built and shared.



Fig. 7

Jeux de Paysages Exhibition (in collaboration with Laboratoire).

Conclusion

In this context and based on the notion of digital materiality we convoke two architectural thematics, ambient and digital tooling, in order to explore the question of materiality. Ambient is considered in its threefold dimension: the cultural and sensitive dimensions, the normative and physiologic dimensions and the physical phenomenon behaviors. These elements become the parameters of a morphogenetic process; the atmospheric morphogenesis logic drives the exploration and the conceptual research; effects, intensity and singularity take place in a digital tooling process; generative and parametric modeling, rapid prototyping and digital fabrication are all contributing to the design process. Our educational objectives aim to control the digital instrumentation of the design and fabrication processes. We reconsider the links between architecture and industry and we wish to merge the art, science and humanities disciplines. These academics programs use the fabrication laboratory resources in order to accelerate the design cycle, “conceive, fabricate and review”, and one to one scale experiments participate to the learning cycle, “think, experiment, perceive”.

Notes

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Debridement
Designing Systemic Networks

In this essay we argue for a more adaptable and self conscious model in design process and construction within the contemporary architectural practice. Information networks drive data packs, facilitating scaleless and seamless distribution of metabolic relations which finally lead to applied processes. Within the pipelines of these networks, information flows-traverses between computational nodes, while through its journey, it is translated, updated, enriched, mutated towards becoming a more responsive and intelligent player. Based on the described diagram, the data carriers are communicating, exchanging data (machinic computation process) or matter (living organism) creating a systemic interplay stimulating evolutionary processes and adaptable “living organisms”.

Thus, through the discussion of selected case studies: Climath, Bloom Project, Krama Proto Tower (research projects conducted in Architectural Association) and recent research projects, we argue that architecture emerges from the digital seeding, where the final outcomes originate from the primordial information system. The designer establishes the initial set of rules and he/she enables the system to produce. The digital domain is the laboratory of today’s architect, where he/she sets the information as input, and then the system computes the variations of possible outcomes. John Von Neumman, one of the pioneers on the development of computing, quoted that in *“The basis of life is information”*. Indeed, by changing the input information, the output also changes. Therefore this comprises a system of control.

Architects perform as design breeders, where they mix the reality given parameters, establishing metabolic relations between the physical and the digital domain and



Fig. 1
Flocking Agents.

vice versa. This rule-based process leads to the evolution of the outcome versions, by increasing the inherent intelligence of the machinic system. The designer produces the genetic code of the “organism”, by setting up the framework of freedom and control -the threshold- of the system, and then the system is informed by its inherent intelligence.

Hence, this essay argues for a design process that is “live”, adaptable and flexible to any conditions that may alter the design output partially or even as a whole. For example imagine that the design process is a kind of a distributed network with nodes and pipelines facilitating data flow where each node is valuable and contributes to the synthesis of the global information. In the same network let’s imagine the scenario that a couple of its nodes and pipelines can’t deliver or process any new information, despite the fact that its neighbour nodes updated and output their own information after a new input which triggered a new cycle of the process. What will happen to the new global information? Will it get scrapped? Will it be incomplete? Could a kind of debridement* process heal the necrotic nodes and pipelines and revitalize the network?

Debridement is the process of removing dead (necrotic) tissue or foreign material from and around a wound to expose healthy tissue...The four major debridement techniques are surgical, mechanical, chemical, and autolytic...Autolytic debridement takes advantage of the body’s own ability to dissolve dead tissue...¹

This healing agency of debridement reflects the act of replacing “outdated” design processes used currently in the architectural practice producing limited design outcomes.

Thus the act of debridement is an act of promoting a new modus operandi towards the “systemic thought”. Finally, this essay will elaborate on that topic through an analysis of a cross-scalar logical network as an architectural mold, and as a system where each very part of it contributes and adapts to an iterative yet seamless communication process. Thus our journey will begin from theorizing the actual process of the practice from the initial idea till the final product/ model/ image/ building through multiple case studies, which depict our method of processing and designing.

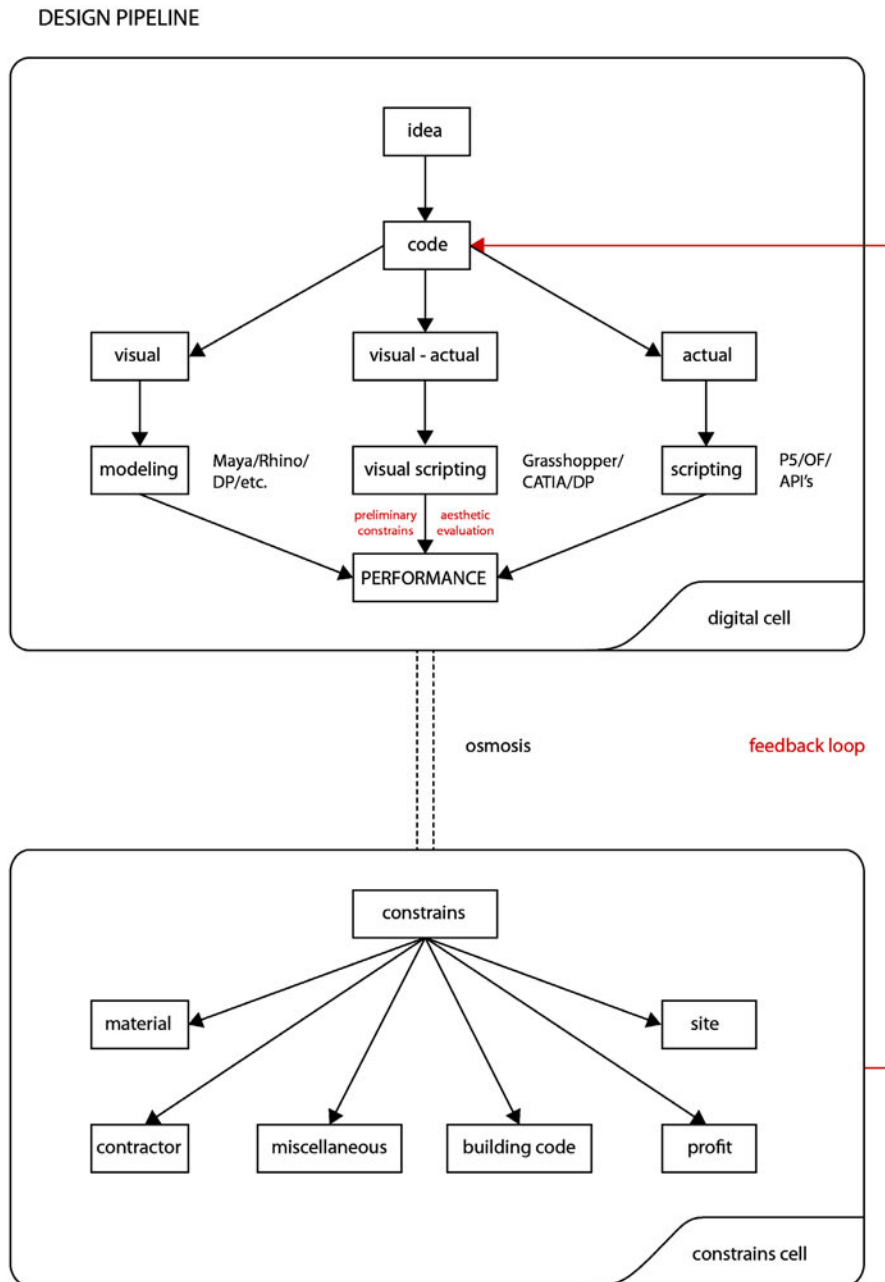
The Design Pipeline

The “design pipeline” (Table 1) is a logical network, a system that describes how input data, the architect’s idea, is translated from analogue to digital, what the languages of translation are and within which context the end-product is being evaluated.

Thus, the beginning of an architectural project is reading or composing a brief. That may be proposed by someone (the client) or imposed by the architect as an act of fulfilling a need that may be actual (neglected or unproposed) or potential, thus projecting to a near future, or utterly utopia. Moreover, the response or a series of responses to that brief is the idea or ideas consisting of an image or series of images (or products, models, sketches, material, etc.) depicting, thus translating, words into shapes. That is the very first act of transcription/transformation produced by an inter-

Table 1

“Design Pipeline” diagram. Logical topology of design process.



nal dialogue, in other words interaction of the “givens” (concrete information) and the “wants”(driven information by the architect(s)).

Once the idea is produced, a second stage of transformation is needed in the digital era. That is, the translation of analogue to digital. It may be theoretical, meaning with no visual representation, or rendered on paper, to something that is projected/emitted from a screen that is colours of pixels and down the line bits and bytes. But how does this translation occurs?

Bits and bytes comprise the primordial soup of the machinic/digital information, allowing data to store on a medium in a continuous or discontinuous manner scattered on available space, where after their assembly they output as human readable information, serving in that way the purpose of the very action of translation. Hence, digital information is driven by the machine code / language which in turn is driven in most cases from a medium that is human readable. The question here would be what is the nature and the characteristics of the medium that drives the machine code in other words the “zeros” and “ones”?

The nature of the medium in which analogue information can be transformed to digital is threefold. Thus, it can be “visual” translation, “actual translation”, or a combination of “visual” and “actual” translation which can be called “visual-actual” translation. Moreover, these media facilitate the communication of data in a qualitative way, in other words in a more accurate or less accurate way. Each of these states of accuracy in turn can be parametrically enabled or non-parametric. The later case can be thought of as a direct implementation of the traditional paradigm of sketching an idea on a paper. In other words Non-parametric modelling (Maya/without history, Rhino, etc.) is falling to the ontological category of existence, where a “creature” is a milestone, a solid gesture imposed by its creator with no many options to operate upon it. Having said that, the operation methods to alter the shape or the nature of that object / creature are linear, where the relation of what is drawn / modelled / projected with what the creator likes is interlocked. In other words, there is no what the object / creature “likes” or can potentially offer in order to create a discourse. Instead, on the basis that the object / creature is not “self-aware” there is only a direct, one way command execution, which potentially restrains the creator of receiving something valuable for the design process, such as feedback.

Moving from the description of the “visual” nature of code and its characteristics, there is also another type, the intermediate one. The “Visual-Actual” nature of code is the combination of modelling (hand drawing) and object / creature - awareness (Grasshopper, CATIA, DP, Maya). Contrary to visual coding, the object / creature has properties. In other words it is self-aware of some basic things that render it able to carry information about its existence and pass, copy or alter that information according to the operations that is instructed to do. In other words, the “visual - actual” coding can be thought of as a kind of parametric modeling, where partially parameters / values, and modelling techniques are combined to deliver the translation of the analogue to digital, as well as to progress, or to transcend to a new level of creativity and design expression. Since the object / creature has properties / attributes within the digital

world, exposed for modification, it will have the capacity of understanding the concept of limit. The mathematical concept of limit* explores the state of what's happening when "something" approaches a specific value. This information is utterly essential for the visual - actual nature of coding, because it establishes and constitutes a dialogue between the creator / designer / architect and the altered object / creature. Since it is a dialogue, or a two way communication, this constitutes a feedback loop. Thus, there exists a seamless communication of visual input and digital output, back to the visual and so on and so forth.

Moreover, the last type of code's nature is "actual" coding. In other words, talking directly to the machine through its language. Scripting is exactly that (C++, Java, Python, etc.). In fact it is the closest possible interface to machine code. We can instruct the machine to do an area calculation for us, load an image, or even to create a form. But the most important question here is what is the nature of the information that is passed-on to the machine? How meticulous this information should be? One possible answer can definitely be, so meticulous as to, firstly the machine to understand what's been conveyed and furthermore, to establish in the digital domain with all of its subsequent benefits, what's been originally thought. In other words, first to translate in a correct manner and afterwards to map this translation, without any ambiguity of the meaning to the desired result and function. For example, if we imagine a vector in space and we want to rotate it by 45° , then apart from specifying this vector we need to specify the plane on which the rotation will take place as well as the origin of the rotation.

Thus, actual coding / scripting is the most powerful way of passing information to the digital domain because it is fully customizable. Everything is being described by numbers, mathematical models, and relations between them. In this case, a vertex of a quad (first order of scale) is self-aware of its existence only because it carries that information. This quad in turn can potentially connect with neighbour ones (second order of scale) adding up to a collective awareness, an so on and so forth, till the global form (n-th order of scale). When a vertex change local coordinates then the quad recomputes its position. In the same fashion, so does the cluster towards Global form. This ontology of self-awareness, boosts the communication between nodes (vertex -> quad -> cluster->...->Global form), facilitating seamless and scaleless flow of information within these complex networks of streamlined data and feedback loops. Thus, after describing the "natures" of the code, the question of how we evaluate this translation is certainly of paramount importance.

Indeed, when we are dealing with networks and streamlined information the criterion of Performance will certainly be predominant. The topology of the network both physical and logical affects its performance. In other words, the speed, capacity and quality of the network to transfer and process data, essentially depends on how its "streams" are being distributed, thus which nodes are connected (information flow), as well as from the capacity of the nodes themselves as to receive, compute and output information.

While this happens in a broader scale, we argue that an architectural / design option is a product of streamlined / network processed information, thus falls to the cat-

Fig. 2
Krama Proto Tower. Fibrous network and ETFE facade.

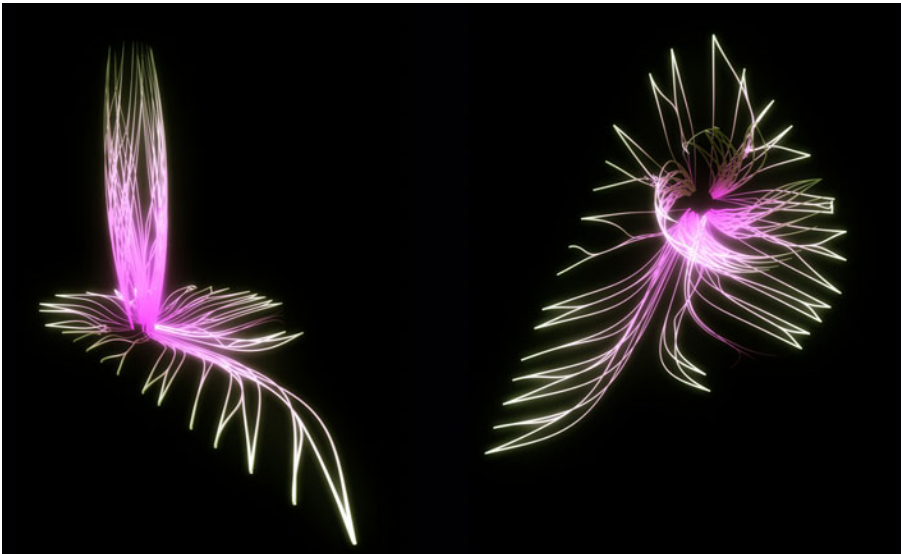
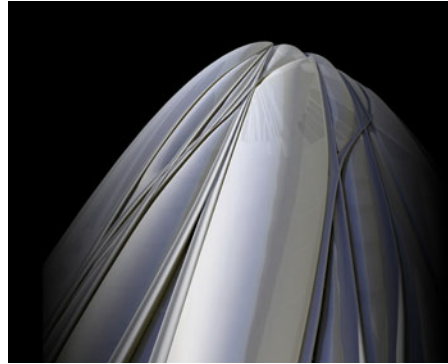


Fig. 3
Krama Proto Tower. Fibers as light operators.

egory of the performance criterion when it comes to selection. In other words, the selection of the fittest solution is the selection of the most performative option, which has been selected through a landscape of possible options.

One example of the description of the “digital cell” is the “Krama Proto Tower” (Fig. 2, Fig. 3) Research project conducted in Architectural Association. This research project is focused on the design of prototypical Tower systems that will adapt on the harsh climate conditions of the city of Tromso in North Norway. Krama Proto Tower is a fibrous performative Tower consisting a satellite city within a city driven by light. The structural system of the tower consists of bundles of distributed self-aware fibers, bundling where the tower needs more support, producing the facade exoskeleton, as well as

beams, within its various structural layers, driven at the same time from the amount of solar gains around the Tower. Moreover, its fibers are hollow playing the role of water collectors and water networks, providing the tower with heated water which is being produced by the absorption of heat from sunlight thus heating the contained water. Furthermore, the skin of the tower consists of ETFE cushions, which populate the pockets being created from the fibrous network. These cushions are filled with “aerogel” which is a powerful insulator which also diffuses the light, and in certain conditions displays different colours on the facade, promoting the Tower as a landmark, an urban actor and as a “light operator”, something that the inhabitants of Tromso need the most. Finally Krama Proto Tower produces energy through piezoelectricity, converting the wind and rain’s kinetic energy falling onto these cushions to light, in order to serve its social as well as its sustainability cause.

Another example is the “Climath” (Fig. 4, Fig. 5) project in the city of Dubrovnik outside the old city walls, which consists of layered functions such as underground parking, plaza, and housing and attempts to replicate qualities and effects of a collective “living” space. The proposal introduces high-resolution micro-articulation of urban furniture as well as energy harvesting. The seating elements imprinted in the surface of the plaza and the swarming patterns of light reflected of the white stone allowing it to glow at different intensities during the night promoting the formation of an interesting atmosphere. The proposal speculates using plaza’s natural exposure to the abundance of sun hours Dubrovnik receives, in order to absorb solar energy through distributed arrays embedded into the pavement. Thus it could consist of a self-powering system, harvesting and distributing energy not only for the plaza but also for the residential part.

Focusing on the residential part, this is also looking at the elements of local physics and culture of Mediterranean living, programming the architectural fabric to reach for the sun and the Old City views through elongated frontal terraces and double height windows. This is achieved by treating the living units as agents of a flocking system, where alignment cohesion and separation principles are in force, thus shaping their distribution towards light and vistas. In that way complex sectional conditions are being generated, opening interstitial patio spaces, skylights and a network of roof terraces throughout.



Fig. 4
Climath. Overview of the project.

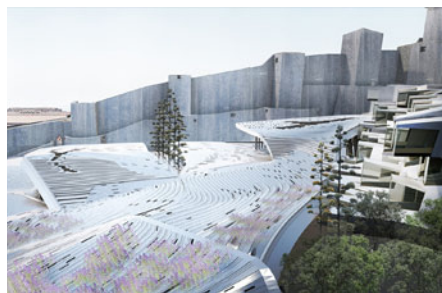


Fig. 5
Climath. Micro-climas and vistas.

Osmosis of two cells

In the previous section we described the construct of the “digital cell”, which is a cross scalar network of seamless and scaleless flow of information towards producing performative architectural / design solutions. The other counterpart construct of the design pipeline is the network within which the properties bearing real-world limits live.

The “constrains cell” will immerse us to yet another scale of the network towards establishing a performative dialogue between design options and constructability.

More specifically, the domain of “constrains” consists a broad set of criteria, which inform / update / alter the design options by influencing and testing its option’s ability to respond to real-world pressure magnitudes. Thus, there is a de facto need for cell / systemic interconnection and interoperation, hence exchanging data as two “streamlined” “live” nodes do, in a different order of scale. In other words, there is a need for osmotic pressures to find their way, bridging the “digital” and “constrains” cells. In that sense, *Osmosis is the net movement of solvent (e.g. water) molecules through a partially permeable membrane into a region of higher solute (e.g. salt) concentration, in order to equalize the solute concentrations on the two sides.*²

The “digital cell” system and the “constrains cell” system, interact and alter each other. Especially, the “constrains cell” acts upon the “digital cell” system with a greater magnitude. That is to say that, using the osmosis paradigm, ideally there is no distinction between which system is more concentrated (hypertonic) or less concentrated (hypotonic). In that sense, when these two systems reach an equilibrium pressure, then they can form a built event. In other words if all the criteria are been covered, architecture establishes itself to the physical / built domain.

For example, an architectural project which is getting built, has several stages such as Competition, Schematic Design, ..., Design Development. After a competition and its rounds of design iterations (Maya, Rhino, Grasshopper, Scripting) were preliminary constrains are applied (Aesthetic, “real-world”), there is the schematic design where the “digital cell” and the “constrains cell” interact intensively. There, “real-world” constrains inform the preliminary design solution, which was selected from a landscape of possible ones, thus informing the “digital cell” anew facilitating a new cycle of the design process. Thus, osmotic pressures from the “constrains cell” release their informed solvents towards the “digital cell” and vice versa. Hence, these new cycles of interactions within different scales produce a vast amount of information and design options which in turn need to be organized coherently, towards promoting the design option which is the fittest possible. Once, the possible solutions are produced then the Design Development begins, where yet another layer of complexity arises where BIM softwares (DP/CATIA, REVIT) facilitate, organize, and release architectural / information to contractor’s node, which in turn may send feedback and trigger the process from the beginning. (Based on Zaha Hadid Architects YOC Project) (Fig. 6).

As it has become apparent, architectural / design process is a complex network of nodes and streamlines where, at any point in the course of the time new information may come in, triggering new cycles. Our current and future need for super fast,



Fig. 6

Nanjing Youth Olympic Centre, Zaha Hadid Architects.

Overview of the project, consisting of two towers and a conference centre.

Render © Zaha Hadid Architects

cost effective, sustainable project execution, cannot be supported by necrotic / static stakeholders, because they slow down the process and limit its potential. This pressure will bring forth a debridement process wherever necessary, in order to “heal” whichever nodes on the architectural / design system are currently datum and unable to provide feedback, revitalizing / enabling them with its agency. Thus, there isn’t more successful schema to describe the osmotic pressures occurring between the “digital cell” and “constrains cell” from how the digital informs the physical domain and vice versa thus producing a feedback loop facilitated by current digital media.

Digital vs physical: Feedback Loop

The proposed case studies consist of contemporary design outcomes where they have been formed, generated and produced based on the aforementioned modus operandi.

Digital techniques as well as analogue / material experiments blend to test and inform each other.

Indeed, “Bloom Project” (figure 7, figure 8, figure 9), is a Research project conducted in Architectural Association, which deals with the creation of a transformable canopy using as material Lycra fabric and stainless steel wire. The exploration focuses in the domain of digital and physical patterning. In other words, to promote and harvest the potentials of the establishing feedback loop on the basis of the question of how a

Fig. 7
Bloom project. Loop redundancy.

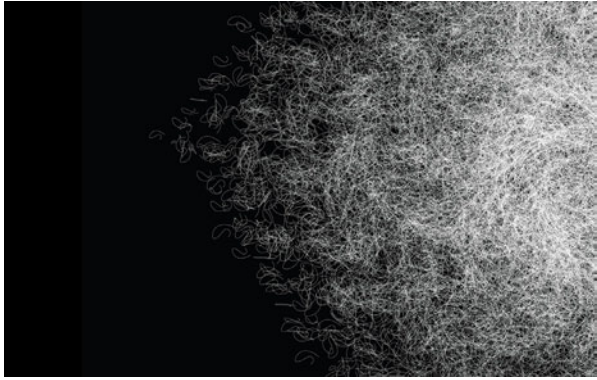


Fig. 8
Bloom project. Physical Model.
Feedback loop patterning.

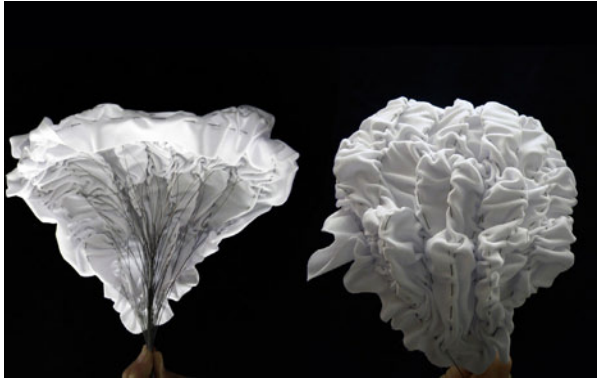


Fig. 9
Bloom project. Micro loops.



physical patterning of some kind affects the contraction and expansion of the canopy locally as well as globally and vice versa. Moreover, this contraction and expansion is driven by light through sensors and servo motors, so when there is no light (e.g sunlight) the canopy contracts while when there is light, the canopy expands / blooms.

Furthermore, the stainless steel wires are woven into the fabric in such a way that there is only one input point of force, where servo motors pushing or pulling the wires producing micro calculations of the fabric towards contraction / expansion globally.

These patterns are digitally designed based on the agency of a looping movement and spread in the fabric as multiple instances, thus producing a “fractal” effect which collectively serves the purpose of the canopy’s function. Moreover, the design options are fabricated and tested to real-world constraints (“constrain cell”) and feedback is output back to the very design of the pattern (“digital cell”). Thus, the pattern is being redistributed accordingly serving the needs of the global function and scenario.

Debridement: Revitalizing the static

Finally, using the term “Debridement” we transfer medical concept into the design process where we imply that datum products consist outdated systems, unfitted for any adaptational, evolutionary or mutation process. Adaptable and responsive design systems which communicate with their neighbors, have the advantage of parametric control of the population through any alternation of internal parameters.

As described throughout the essay, while the designer is sowing his/her digital seed, the code triggers the behavior of local agents to update-adapt to global conditions, and therefore the algorithm works from local to global and vice versa. Similar to the agent based process of the maggot or autolytic therapy of debridement, the new paradigm comes to replace, enrich, amend, trigger and revitalize the datum members of the current architectural framework and practice. The outcome consists a total parametric creature which based on its inherent logic can perform as an adaptable and site specific organism.

Thus “Debridement”, within the network of architectural process, is the act of replacing “dead” or “datum” nodes and pipelines with active ones. That is to say that a “live” node which promotes adaptability, flexibility, transformability, parametrics, constantly processes information and establishes seamless-scaleless inter-operations between data from different systems, increasing the performance of the design process. Hence, the quality of the responsiveness is critical for such an integrated system, since either it will empower the stream of information or deprecate it. The old-style paradigm is all about a deprecated or one way communications where no feedback loop is established, while potential alterations or corrections to the primary scheme are lengthy, time consuming and mainly limited.

Notes

- 1 Debridement (Encyclopedia of Surgery, 2012)
- 2 Osmosis (Wikipedia, 2012)

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Origami Tessellations in a Continuum

**Integrating design and fabrication
in architectural education**

Origami tessellations populating the digital surface

In the range of projects that define the digital avant-garde of the 00s, the notion of surface maintains its overall form generating function and gains rigor through the accelerated growth of digital fabrication techniques. Advances in architectural geometry, an interdisciplinary field currently emerging at the border of differential geometry, computational mathematics and architectural design and engineering¹, (Pottmann 2007) provide solutions for the actual construction of architectural free-form surfaces, segmenting the overall surface into simpler parts, a process also known as panelization. In most experimental digitally generated projects since the mid 00s, surface becomes an integrated aggregate or a 'synathrosis' of non-standard components that facilitate overall architectural substance, each component requiring relatively simple fabrication procedures. The concept of surface as synathrosis² pertains to an assemblage of monads that individually express the common logic of the group, explicitly articulated within a computational system. The emphasis lies in the design of self-supporting, material efficient patterns that populate the surface allowing parametric part-to whole interrelations.

Surface division into a population of elements seamlessly fitting together comprises a tessellation. Our research hypothesis revisits a retro mode of tessellating, the geometry that originates in Origami, the ancient Japanese art of paper folding, in the context of the evolving computational design and fabrication methods. Origami tessellations are not uncommon in 20th century architecture. As the overview of paradigmatic projects developed in the next section makes evident, Origami tessellations in architecture are most usually encountered as static structures, folded plate shells, with applications as large spanning roofs, load bearing walls, or combinations of both. In this essay we also explore the impact of tessellating upon the kinetic behaviour of lightweight architectural surfaces focusing upon geometric transformations of architectur-

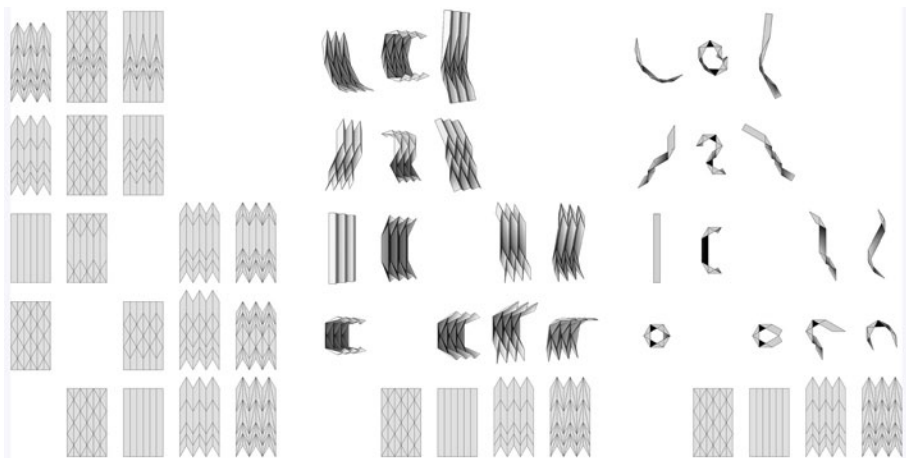


Fig. 1

Combinations of elementary Origami tessellations: Yoshimura, Pleat, Miura and Fishbone. Simulations with Rigid Origami software by T.Tachi, Sophia Vyzoviti & Pablo de Souza, 2012.

ally relevant Origami patterns - the Yoshimura, the Miura, the fishbone and standard pleats (Fig.1). We test the effect of pattern geometry upon the surface's kinematics and distinguish between two generative processes: (a) 2d pattern transformations based on repetition, arrays, and serial variability, and (b) profile generated patterns that are constructed from a desired section and further manipulated through generative modelling.

Within the context of digital fabrication advances architects are concerned both with tectonics of assembly and with synthetic surface and material effect resulting to intricate patterns through the aggregation of building materials³ (Iwamoto 2009). Iwamoto (2009) classifies folding as one of the state of the art digital surface fabrication techniques. Certainly as a method for digital fabrication folding entails the development of three dimensional components into two-dimensional patterns ready for cutting by lazer, water-jet or plasma cutters. While geometric development in two dimensions has been employed in pre-digital tectonics, arts, and crafts it is today largely facilitated by software. The pre-digital unfold or crease pattern which traditionally required intensive geometric calculations can be easily achieved in modelling software – by the unroll or smash commands in Rhino and employing applications like Pepakura Designer. Despite the fact, the design generative potential of folding has been neglected in computational architecture during the past few years. In this paper we intend to revisit the design generative potential of folding, by embedding it within advances in digital modelling, exploiting its digital fabrication facility and enhancing its performance potential.

Evolution of Origami tessellations in 20th century architecture

During the 20th century many architects have explored the structural capacities, the conceptual symbolism and spatial possibilities of creating architectural forms by importing the knowledge of Origami art into architecture. The paradigmatic projects we

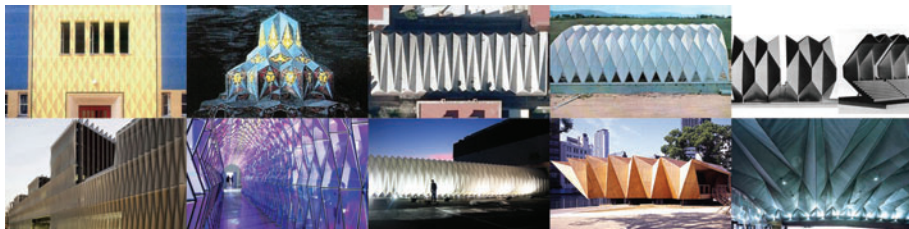


Fig. 2

Origami tessellations in contemporary architecture (top row from left) (1) Facade detail by Bruno Taut, Berlin-Grunau, 1912, (2) Kultusbau by Wassili Luckhardt, 1920. (3) Decks of the dining room of the Technical College of Tarragona by Eduardo Torroja, 1956 (4) Experimental timber cover by Renzo Piano, Genova, 1965 (5) Stadium and sports complex by Jorn Utzon, Jeddah, 1967 (bottom row from left) (1) Biomedical Research Center by Vaillio & Irigaray & Galar, Navarra, 2011. (2) One way colour tunnel, by Olafur Eliasson, San Francisco Museum of Modern Art, 2007. (3) Foldable Plastic Tube by Mats Karlsson for Stockholm Design Week, 2008. (4) Wooden Pavilion in Nakanoshima Park by Ryuichi Ashizawa, Osaka, 2009. (5) Passenger Terminal by Foreign Office Architects, Yokojama 2001.

display here (Fig. 2) provide a chronological evolution of Origami applied into architecture, focusing upon the form-generative, ornamental and structural properties of the most architecturally celebrated Origami pattern, the Yoshimura.

The conceptual transformation of a two dimensional surface into a patterned, rhythmic and multiply folded plate structure comprised a recurrent theme in architectural avant-garde. The facade made by Bruno Taut at Falkenberg in 1912 represents the geometric pattern of Yoshimura. Taut used to emphasize the surfaces of facades by using prolifically contrasting brilliant colour ranges. Taut was probably familiar with this design through the many publications of the beginning of the century that explored these new knowledge that connect crease patterns with mathematics, geometry and consequently with architecture. We use this example as the very first direct reference of Origami art imported, though only graphically into architecture.

Drawings of Wassili Luckhardt, at the time of the "Gläserne Kette", started from a crystallographic abstraction of Switzerland Mountains⁴ (Nerdinger & all, 2002). In a few of his projects the influence of geometric exercises of representing primary figures by folding paper is evident. That kind of exercises probably inspired the ability of finding and imagining complex and innovative forms made by folding that emphasizes internal spaces in contrast to the mass of an opaque crystals and minerals. Using sequences of folds W. Luckhardt created spaces full of rhythm and vivid contrasts of light and shadows.

Among the following decades 30, 40 and 50s crease geometric patterns inspire plenty of artistic works, lighting fixtures, furniture and interior designs as the circular Yoshimura dome of the dining room of the restaurant "El Coto" in Madrid, made by the architect Luis Gutiérrez Soto. In the early works by Eduardo Torroja, Pier Luigi Nervi and Felix Candela we encounter folded plate concrete shells, material efficient structurally active surfaces that are extremely thin in proportion to their load bearing capacity⁵ (Bechthold, 2007). Since the late 60's folded shells also appear in timber, pvc, as well as cardboard. While the structural and plastic qualities of Origami tessellations in architectural surfaces prevail, little has been achieved with respect to kinematics.

According to Fernando Cassinello not only were the complexities of calculation that halted the application of folding patterns into architectonic structures, but also the aesthetic prejudices in a new way that would break with the doctrines in vogue, giving the spectacular triumph of aggressive, dynamic and personal architecture of Frank Lloyd Wright, as a favourable factors to acceptance. To this would be added the expressiveness and movement of the forms developed from crease patterns in contrast with the clean and pure rationalist, purists, and neo-classical volumes, in which the inclined line and planes had no place in its immutable creed of parallelism and orthogonality (Cassinello 1961).

The completion of the construction of the passenger terminal at the port of Yokohama in 2002, directed by Alejandro Zaera and Farshid Moussavi of Foreign Office Architects - based on their first prize in the international competition held in 1995- has re-established within architectural practice the implementation of geometries derived

from faceted surface elements inspired by Origami. In the past decade, folding has fruitfully expanded its popularity among students of architecture as a resource for formal exploration. Conducting working models through folding and cutting paper has helped the understanding and development of complex geometries as well as their corresponding spatial mechanisms.

From Fröebel to Tachi: Origami as a teaching tool in architectural design education

Material driven form generation experiments have a long tradition in the architectural avant-garde. At the preparatory workshops led by Joseph Albers at the Bauhaus during the 20's form generation was directly done with material handling⁷ (Bergdoll & all 2009) intending to familiarize students with abstract spaces deriving from surface transformations caused by the stress and strength of paper. Since the mid 90s surface transformation morphogenetic studies in paper and other sheet materials have been exacerbated and associated with strategies of folding, surface manipulation and the creation of artificial terrains⁸ (Allen 2011). Material computing is a recent discipline specific term that describes the analogue form-finding processes complementing the new digital design tools that might in fact be described as quasi-physical form-finding processes⁹ (Schumacher 2007). Following the evolution of the notion of surface in contemporary architecture, we observe that digital design methodologies have paradoxically revamped physical modelling, in an expanded notion of material computing which not only complements but also challenges the overall form, distinct component, and texture generation.

The course *Folding Architecture*ⁱ taught by the authors at the Department of Architecture, University of Thessaly during the spring semester of academic year 2011-12 is embedded in the tradition of material driven form generation processes in architectural education and investigates combinatorial methodologies that employ both computational tools and material processes outlining interdependencies between the two. The course focuses upon the design generative potential of folding as a retro-novel genre of tessellating the digital surface. The didactic methodology of the educational project interweaves thematic research in Origami, papyroplastics, folded plate and deployable structures, single surface architecture and advanced architectural geometry.

In the introductory exercises, the drills that complement the four lectures embedding the scientific relevance of the design assignment, the didactic methods of Friedrich Froebel and Joseph Albers are combined with traditional Origami techniques and state of the art digital simulations (Fig. 3).

The first thematic lecture *Vanguard Childhood: A new educational paradigm, Friedrich Fröebel and the abstract Origami* demonstrates the origins of the relation between Origami Japanese art and European artistic culture in early 20th century. The corresponding drill entails the construction, of a number of Origami objects such as the dove, the tulip, the crane, the waterbomb, the swan, chicken as well as the geometric construction of the several regular geometric flat figures that can be made by different folding positions of the equilateral triangle displayed in the *Fröebel album* (Fig. 3).



Fig. 3

Folding Architecture course didactic references (from top left) spread from Fröebel Album with Folding exercise¹⁰ (Bordes Caballero, 2007) spread from Senba-zuru Orikata 1797, preparatory course directed by Josef Albers (Bergdoll et al, 2009) covers of publications by Sophia Vyzoviti.

The second thematic lecture explores the early influences of Origami art in Modern architecture. The corresponding drill focuses on devising experiments that activate potential transformations of paper into a three-dimensional surface. The exercise refers to the methodology of the preparatory workshop by Joseph Albers at Bauhaus, where the exploration of potential forms is directly related to physical models. According to morphogenetic experiments outlined by Sophia Vyzoviti in her publication *Folding Architecture*¹¹ (Vyzoviti, 2003) paper surface is considered as an operational field where discipline in time, sequences of transformations are applied by folding, pleating, creasing, scoring, cutting, pressing, rotating, twisting, bending, wrapping, interweaving, compressing, enfold, extending, and balancing.

The third thematic lecture focuses upon the influence of Yoshimura patterns on folded plate shells as demonstrated in the work of Torroja, Candela, Breuer and Nervi. The corresponding drill focuses on tessellated shells produced by direct folding in sheets of paper. This technique generates shells by profile manipulation that manifest kinetic behaviour in terms of rotational and translational deployment.

The fourth thematic lecture focuses on current development of surface architecture in the context of the evolving computational design and fabrication methods. The corresponding drill focuses on digital representations of Origami tessellations on the basis of developed crease patterns employing the open source application Rigid Origami Simulator created by Tomohiro Tachiⁱⁱ. The particular drill familiarizes students with a technique of transferring physical to digital object data, generating computable models from direct folding experiments that enable their further architectural calibrations in terms of digital design and fabrication.

Architectural Design Development

Having established their computable geometry, the fundamental question is how Origami tessellations become productive in architectural design development. Design processes, valuable as they are in terms of didactics, need to be substantiated by their results. The section demonstrates design development processes and design outcomes, making evident the range of applicability of Origami tessellations in integrating design and fabrication in architectural education.

Design method

The notion of generative modelling as a shift of focus from objects to operations, defining form as a sequence of processing steps, rather than the end result of applying operations, is employed in the design development method. Based on a model of workshop teaching, the studio process relies primarily on modelling and prototype fabrication and explores the design potential of Origami tessellations integrating geometry, materiality, and performance.

The sequence of steps in the design development oscillates between physical and digital modelling (Fig. 4) and in an outline includes:

- Analogue form-finding based on Origami principles by direct folding that leads to intuitive, freeform, pattern variations

Fig. 4

Characteristic phases in design development process making evident operational shifts from physical to digital modelling. University of Thessaly, Department of Architecture, Design Studio Folding Architecture, Sophia Vyzoviti (faculty) Pablo de Souza (teaching assistant), Giorgios Amvrazis, Irgen Saliani, Apostolia Sofiadi (students) 2012.



- Developed crease patterns, processed according to the two colourable Origami rule
- Deployment simulation in Rigid Origami Simulator
- Transformation of digital objects in Rhino
- Revised developed crease patterns
- Fabrication of models with cutting plotter and laser cutter
- Prototypes in soft and hard material combining paper, plastics, meshes, and fabric
- Kinetic behaviour study of the prototype, physical deformations that exceed simulation
- Evaluation and preliminary design development.

Range of applicability

Research outcomes in terms of architectural design that were produced during the *Folding Architecture* course include three classes of architectural products: static shells in the genre of folded plate structures, kinetic shells in the genre of architectural textiles, and polymorphic reconfigurable objects.

Static shells in the tradition of folded plate structures make evident the versatility of digital morphogenesis facilitated by computational modelling and fabrication tech-

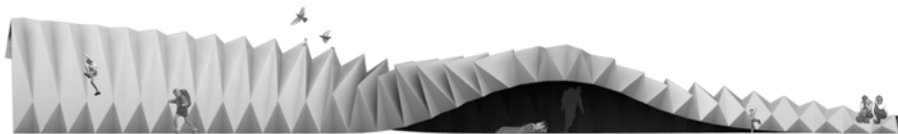


Fig. 5

Forest shelter. University of Thessaly, Department of Architecture, Design Studio Folding Architecture, Sophia Vyzoviti (faculty) Pablo de Souza (teaching assistant), Artemis Papachristou and Tatiana Vasiliadou (students) 2012.

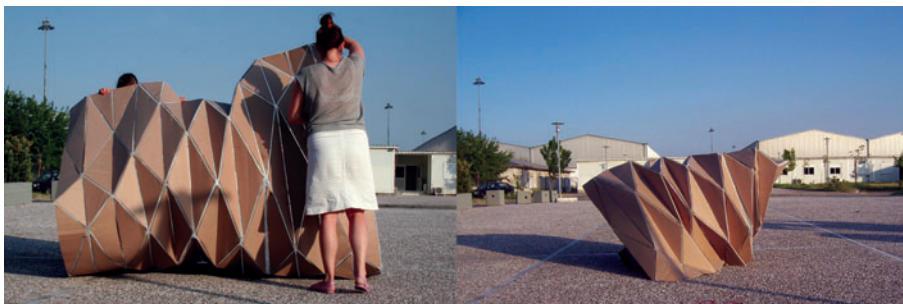


Fig. 6

Kinetic shell prototype. University of Thessaly, Department of Architecture, Design Studio Folding Architecture, Sophia Vyzoviti (faculty) Pablo de Souza (teaching assistant) Vasilidiki Dimou, Kostis Maniatis, Beatriz Borrego and Vasilidiki Berberidu (students) 2012.

niques. While their architectural calibration maintains an elementary space enclosing capacity compared to their historic precedents their regulating geometry is variable. Digital modelling enables a seamless integration of scaled, tilted, rotated components within a continuous system. A parametrically differentiated Origami tessellation accentuates architectural performance by enhancing morphological flexibility and therefore diversifying possible modes of habitability (Fig. 5).

Kinetic shells in the genre of architectural textiles are tested in the studio with a range of material substances combining rigid and soft sheets. The groups explored the deployment ability of each shell in an indeterminate series of transformations alternating overall enfolding of the pleated shell in order to produce minimum inhabitable spaces (Fig. 6).

In terms of kinematics, Origami tessellations commonly manifest translational and rotational deployment, flat packaging, axial rotations, and more rarely axial revolutions. Translational deployment produces the spatial effect of oscillating tubular forms that contract and expand maintaining constant enclosure. Rotational Deployment produces the spatial effect of oscillating spherical forms that allow for variable boundary enclosure. Flat-packaging produces the spatial effect of a diminishing footprint. Revolutions and axial rotations produce the spatial effect of alternating concave and convex enclosures. Two formal states comprise minimum and maximum values the object achieves: developed state and flat package state. In between the two, objects acquire a variety of vault configurations producing an oscillating tubular spatial effect. Translational deployment was evident in all steps of the transformation from vault to flat package.

The third kind of design derivatives - the polymorphic reconfigurable objects-transgress the mandate of single surface. Origami tessellations provide the regulating geometry for component formation allowing for assemblage flexibility and multiple recombination options. In this genre of objects we observe the similarities between Origami and Tangram.

Prototyping

Fabricated prototypes confronts the geometry of surface transformations with material effects, incorporating factors such as gravity, time, and human participation. The full spectrum of shape change in the physical, animated by human activation prototypes was not evident in the digital simulation. Formal instability and plurality is triggered by the interaction between individual and kinetic prototype (Fig. 7).

While testing the fabricated prototypes we observed that Origami tessellations, in performance bare the potential to generate shape changes autonomously, operating as a morphological automaton. This emergent performativity, which is open to interaction and integrates the unpredictable, can be attributed not only to the systems' intrinsic geometry or its material consistency but also to the artefact's potential appropriation by human agency.



Fig. 7

Transformable furniture prototype performance at the kindergarten. University of Thessaly, Department of Architecture, Design Studio Folding Architecture, Sophia Vyzoviti (faculty) Pablo de Souza (teaching assistant) Eleni Marinakou, Stavroula Psomiadi and MariaTsilogianni (students) 2012.

Conclusion

The traditional disciplines of artistic expression are reinvented every day, transformed under the influence of technological advances that offer us greater accessibility to fields of action and reflection that were far away socially and physically until now. Architecture has traditionally been known as the art that covers the three major artistic disciplines. In the current contemporary context of creation and thanks to the influence of the new artistic languages and means of creation, the architectural project may be ephemeral, ethereal and audiovisual, a temporary urban installation, and no longer exclusively eternal heavy and immobile. Cross disciplinary of artistic genres that today represent diversified cultural production offers new opportunities for action and reflection, research and creation.

The course Folding Architecture partakes in this new phase of hybridization and cross-breeding inherent to contemporary creative trends, in which the act of creation has shifted from the individual to a practice of commons, a multidisciplinary community of creators, where collective work is a priority, focusing in the collaborative nature of artistic processes. Traditional art of Origami which has served and still serves as creative inspiration enhances its maximum expressiveness as a medium and as a catalyst for research. As a field of interference between innovations in artistic media, spatial geometries and building materials that enable multiple and heterogeneous applications of architecture, it offers to us a global vision and at the same time a focal point, a thread of narrative intensity and creative potential.

Acknowledgement

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i Course description available on <http://www.arch.uth.gr/en/studies/course/482/8>

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**Propagation
Feedback
Reverberation**

Propagation

Throughout the evolution of architecture in history, the act or process of addressing the increasing complexity that coalesced from the fields of technology, material systems manipulation, spatial sensibility, social structure and culture involved information processing intended as its organization and transmission throughout the growing subjects and levels involved in the design and construction process. When commerce intensified and the first transaction value exchangers (i.e. forms of money) aroused, the number and complexity of transactions overcame the capacity of the brain to keep them sorted out; it became thus necessary to introduce a way of recording them for future consultation. Whether pressing cuneiform shapes into clay or sequencing knots in ropes, the invention of information recording and processing technology was the first example of brain function externalization, implying a code (a rule to convert a piece of information into another object or action, not necessarily of the same nature and kind) and a necessary degree of abstraction¹.

In the field of architecture, the relations among building practice and design/planning have grown increasingly articulated and intricate, with mutual interrelations and rich information flows among design, construction and communication, where the know-how of each process stage was embedded into the subjects involved, thus forming a seamless nexus that converged in the emergent figure of the architect-master builder. The recording and transmission of information from one step to the other followed the same necessity of organization beyond the brain's own capacity. Such complexity and abstraction started to be addressed through representation²: building up from the projective technology that we, as humans, developed as symbiotic with the projection mechanism of our camera-eye vision since the Nazca pictorials, the aim of representation is to both unfold and compress a conceptual topological n-dimensional manifold in a sub-space of lesser dimension (which is the medium – typically in architecture the projection goes from 4D to 3D to 2D) through a likeness or an image. Treatises, from Vitruvius on, epitomize the scale and range of representation as symbolic substitutive description of the architectural object, with opposite cases such as Leon Battista Alberti who predicated a division between design concept and building (or between brain and hand) on one side of the spectrum, and Philibert De L'Orme and Viollet Le Duc on the opposite side who try to address both aspects of visualization and construction process giving a visual account of the supposed result and the set of instructions for its realization. Regardless of the different positions though, representation by its very nature is oriented to the object, placed before (by its definition) and careless of the process that brought the object itself into being. Furthermore, abstraction excludes implementation, so even a representation of a process will always disregard its internal dynamics.

The next big historical intensification that occurred with the industrial revolution dramatically pushed further the level of abstraction in processes through the division of labor, stripping the know-how (which is an embodied knowledge) from each subject and flattening their singular expertise to an interchangeable piece performing a set of simple operations in a global mechanism (which is a representation of acts). The mutual enforcement that occurred among positivist philosophy, standardization and op-

timization processes and the worldwide diffusion burst of industrial means of production further widened the gap between representation and construction promoting an increasingly reinforced separation among the various steps. Abstraction as interpreted from a linear deterministic point of view³ deals with the acceleration of complexity by fractioning a whole in a set of simple, repeatable, context-independent actions, within which standardization contributed in promoting an idea of optimization that subjugated intensive material processes to a superimposed design. Industrial revolution also pushed the shift from contextual to analytical, as the precondition for its own diffusion is universal repeatability; in such perspective, abstraction for its own nature progressively eliminated the contextual dimension, helping separation between concept and making, fostering a process by which objects and systems are defined similar in form to their meaning (semantics), while hiding away the implementation details (the embodied knowledge, i.e. construction processes, tectonics, material systems and intensive properties involved). 2D representation also boosted the industrial tendency to converge towards the flat condition and Euclidean geometry as they facilitate mass production economy, enforcing an idea of rationality as belonging to a finite set of shapes and rules.

The actual divide between the conceptual design phase and its subsequent realization as separated and simply overlaid phases unable to influence each other reveals the closed, goal oriented nature of representation: it shows a manifest object that was already conceived without the possibility to change it.

Simulation, on the other hand, is the imitation of the operation of a real-world process or system over time⁴. Its definition marks a significant difference with representation by showing a dynamic and process-oriented nature. The intensification of computational power along with the emergence of complexity and non-linear based theories brought to a different stage where the use of simulation became necessary in order to understand a system behavior over time, since emergent phenomena are dynamic (or, better, a property is not emergent rather it becomes emergent), detectable but not predictable (the initial rules that govern a system are deterministic and explicit but they do not include nor are an index of the system's emergent potential, function and performance over time) and not quantifiable (emergence is qualitative, not quantitative⁵). The increasing of possible resolution made possible through big data manipulation and the shift towards dynamic models set a turning point for the role of representation in general and more specifically in the architecture workflow. The pattern-seeker/pattern-maker nature of our cognition model extended through intensified computing enabled the embodiment of emergence and complexity thus evolving our recognition criteria from patterns of static figures to dynamic changing patterns of singularities which are evaluated and recognized in their formal, topological and performative aspects at once. It is finally possible to overturn representation if we cease to encode relationships between singularities and identities – opposition, analogies, fixed typologies etc. – but instead in terms of constitutive inequalities (dynamic relations which generate difference). Content and information are not related anymore to a fixed catalogue of objects or symbols, rather to a dynamic web of intensities and continuously evolving relations (the information ecology to which they belong) and its own topological body; this dynamic of relations and embodiment makes it more context-sensitive (deployable), resilient (heterogeneously pregnant), and articulated.

This renewed context calls for a change in the design process, from the actual divide between conception and realization fueled by representation to the propagation of active vectors of exploration in complex realities rich of turbulent dynamics. Moreover, those vectors need to be necessarily proactive and speculative⁶ and not a sheer reflection of the context.

Feedback

How then is it possible to bridge the actual divide between design and making? As simulation allowed a more dynamic and open-ended exploration, it is crucial to understand its paradigm shift and implications to its very core: as Manuel De Landa said, this entails topological, intensive and population thinking⁷. Surely the definitions of set of relations becomes of primary importance, but beyond that it is even more important to define the objects of such relations and how both are modeled. Modeling itself is an operation that has to do with the spatialization of information. If we come to the understanding that matter itself is information based⁸ and ultimately its constructive aspects derive by its own relations between behavior and form then it comes also clear to our minds why programming is the most important paradigm of our present days. Deriving from object-oriented programming, object-oriented philosophy⁹ considers the possibility of a reality of objects in constant interaction in which relations, gradients and intensities are objects themselves and therefore can be programmed in their constitutive characters and behaviors. The most radical consequence of this paradigm shift then is a change from the definition of a global, superimposed and non-changeable, non-negotiable form and shape to the programming of the constitutive characters and behavior of interacting objects. Material and geometric properties, environmental fields can then be programmed as initial rules of a system that then can be simulated and its results evaluated and interrogated (Fig. 1).

Another consequence of the increasing resolution that describes the fabric of reality in our models and theories, as well as the non-linear feedback typical of complex systems is to have recently propelled into several branches of computational design research an increasing leading role to performance as evaluation criteria (especially biomimetically inspired and pioneered in sectors such as aerospace engineering and automotive). Such variable is not new in the design field, yet its role in creative disciplines should be very different from the one it occupies in science and engineering. The latter fields are goal-oriented: performance optimization is the minimization of a function within precise conditions where the space of possible configurations admits one universal optimum: it is the case of finding the shortest path between two points on a given medium. In other disciplines it could be the task to shape a fork in order to produce a 440 Hz sound wave, or the work made to tune all the gear components of a speed skier, the goal is to go as fast as possible along a straight slope. Taking this same paradigms in creative disciplines, performance can be aimed towards facilitating the search for multiple optima in the space of possibilities: a guitarist has its own preferences in terms of instrument (sometimes dictating specifics on how his instrument should be made), amplifier and effects; a snowboarder fine tunes his own gear in order to ease the creation of new tricks. In both cases, the idea is subject-dependent, proactive (anticipates events rather than being their reflection), with an initial push and an open-ended goal.

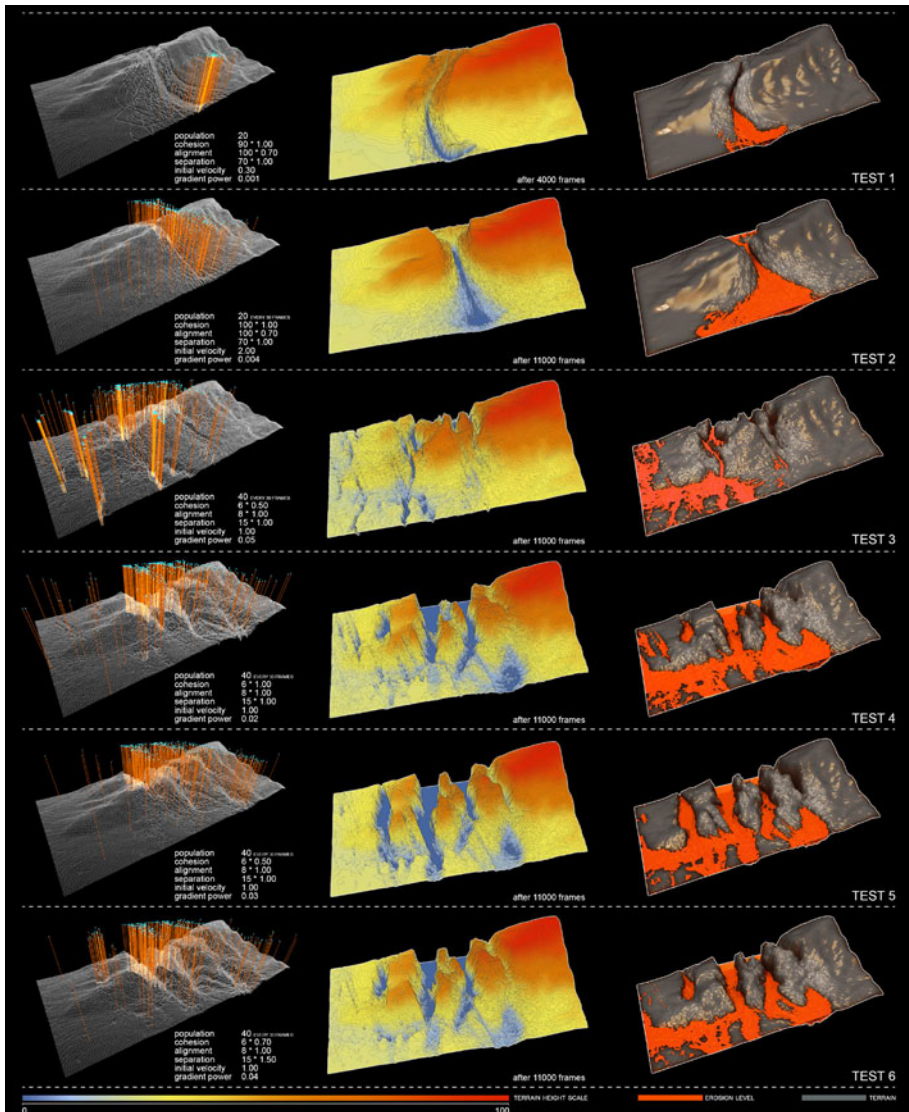


Fig. 1

Simulation of riverine formation through agent system. Cataclysm - project developed by Ervis Lapi, Davide Minutelli, Alessandra Poli & Davide Lanciotti for a3 2012 Studio – 100YC at Università di Bologna.

Far from using performance to drive design towards a supposed objectivity through which it justifies aesthetic choices, I am making instead a case where proactive strategies exploit agency¹⁰ through simulation shifting the “conception” (as prefiguration of a self-sufficient idea) into an “inception”, an initial speculative and subjective vector of exploration for the active propagation of the design exploration. Intensive material properties, environmental gradients and relations are encoded as characteristics

and operative constraints of interacting objects; the multiple feedbacks of such interactions (including potential emergent phenomena) need to be explored through simulation¹¹.

Reverberation

Given the unquantifiable nature of emergent phenomena, the form of a system (both its shape and internal organization) or the measure of its simulated performances, no matter how accurate, are no index of its possible functions (while those still depend on the former ones), as function is related to intelligence and its contextual application. Intelligence can be defined as the capacity to predict performance in multiple domains¹² and it can only be defined in context, relating it with performance as the amount of work required to complete a certain task (or series thereof). Such relations are established in ways and with results that depend on the structure of information itself, as information is the basis of cognition and leads to knowledge and the definition of intelligence. Cognition and information do not exist if not spatialized through a body: without a spatial body, no difference could be established between data and then extracted information. Given this assumptions, intelligent behavior emerges out of the interplay between brain, body and environment. Embedded Embodied Cognition (EEC), whilst referring mainly to human condition, can be extended in a broader meaning for any system which is able to learn (taking as given that the system has a body and operates in an environment). Intelligent behavior emerges from the interplay of the three factors involved, where the environment is an active player (i.e. a programmable object) and not just a background. Embodiment refers to the idea that the bodies' internal milieu (internal states and processes) influences the kinds of cognitive processes that may arise at several levels in the system. Embeddedness considers the body-world interaction as a constrain to the possible behaviors of the system, which in turn influences and constitutes the cognitive processes emerging from such interaction. Internal body states and body-world interaction influence a system's cognition; body, world and brain together in their interrelations allow intelligent behavior to arise as a system property.

The reverberation of information in embedded and embodied cognitive behavior in dynamic systems of constructive agents leads to the emergence of intelligent behavior, not dissimilarly from those who regulate metabolism in a biological organism, from termites building their mound or from geological processes shaping a land. In such context, form finding strategies do not operate as main optimization drivers, but as a participatory behavior that steers and constrains locally the agency of speculative exploration vectors, much as laws of gravity, motion and current fields constrain the flight trajectories.

The ultimate aim of generative processes is speculative and open ended, openly exploring the space of possibilities through the simulation of non-linear systems endowed with agency and initial exploration vectors. Intelligence is searched as emerging property of the system by encoding designed tectonic behaviors in the agents. Their propagation, the multiple feedbacks received and the reverberation of information on the cognitive processes of the system (which includes the environment as well) produce a variety of possible options for the formation of architecture through behavior programming, thus bridging the design-making existing divide.

Case studies

a3 100YC projects

a3 is the acronym for Architecture and Architectural Design 3 studio at the Faculty of Engineering, University of Bologna. The studio 2012 topic investigated the implications of intelligence as embodied and embedded into the architectural system itself as distributed processes of structured information exchange and its inextricable environmental interrelations. Intelligence tendency is to be ubiquitous and embodied into organisms and their environments alike; in such condition ecology expresses itself in its very core definition of abundance and distribution of resources through information exchanges at all possible scales of complexity. Such embodiment and embeddedness was investigated exploiting swarm intelligence (through the propagation of agent-based systems) coupled with multi-scale form-finding processes as a means to unleash open-ended creativity and a potential range of affects. Such agent-based systems co-operated (collaborating or competing) within intensive environmental force-fields, proactively engaging the body-mind-environment relations, from the logics of material organization to the reverberations at several system scales.

As part of 100YC project, focused on speculative, visionary projects for the city of Maribor in 2112. The outcomes were presented in a conference within Maribor 2012 European Capital of Culture event and exhibited in the Slovenian Pavilion (as well as in the Australian Pavilion) at the 2012 Venice Biennale.

The projects tackled seamlessness and scalelessness articulating the general concept of proactive propagation|feedback|reverberation in several ways, but all exploiting forms of intelligence connected with the encoding of building behaviors in the core processes, thus extracting the design as a result of the dynamic system exploration. The morphologies presented are an account of the development reached should not be thought as fully finalized architectures, as the morphogenetic processes involved could continue perpetually over time (as it is for termites opening and closing ventilation channels in mounds). Also, the initial conditions have been intentionally kept scaleless, in order to leave possible open interpretations according to the scale of application. For instance, a particular implementation of reaction-diffusion processes (the Fitzhugh-Nagumo model) was explored through Continuous Cellular Automata to come to an understanding of how such processes articulate space and matter over time (Fig. 2).

In other cases agency and simple behavioral rules were implemented in multi-agent systems, in order to be able to program progressive behaviors of raising complexity which led to emergent constructions and spatial patterns. Constructor agents deploy fibrous structures (which are in themselves very interesting for their capacity to create gradient and uncertain conditions between surface, strand and openness) by material deposition coupled with local form-finding techniques at multiple scales. Those agents can interact with any data field coded in the environment (in this case, global radiation affects the cohesion, separation and alignment factors – Fig. 3).

The release of material, as a coded property of the agents, can be then programmed so to be modulated by condition (i.e. densifying or rarefying the local material sys-

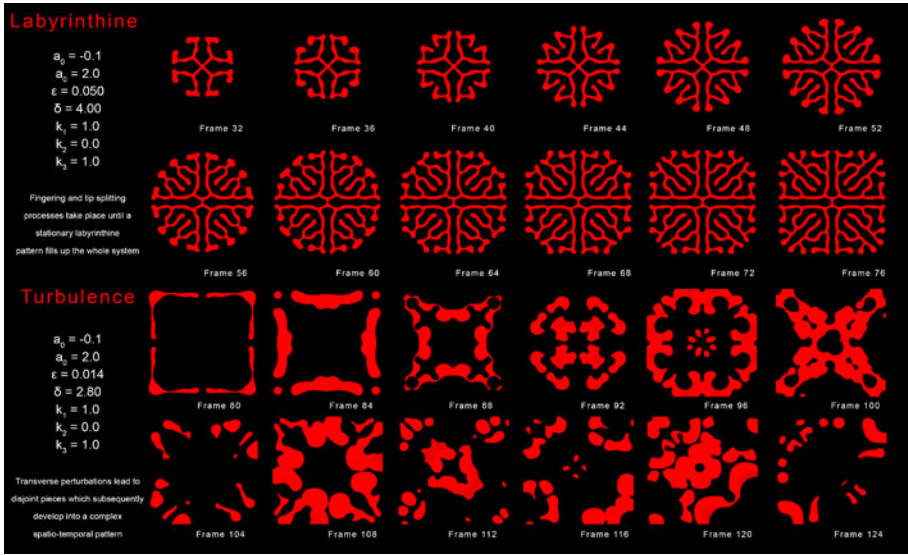


Fig. 2
Fitzhugh-Nagumo reaction-diffusion pattern chart.

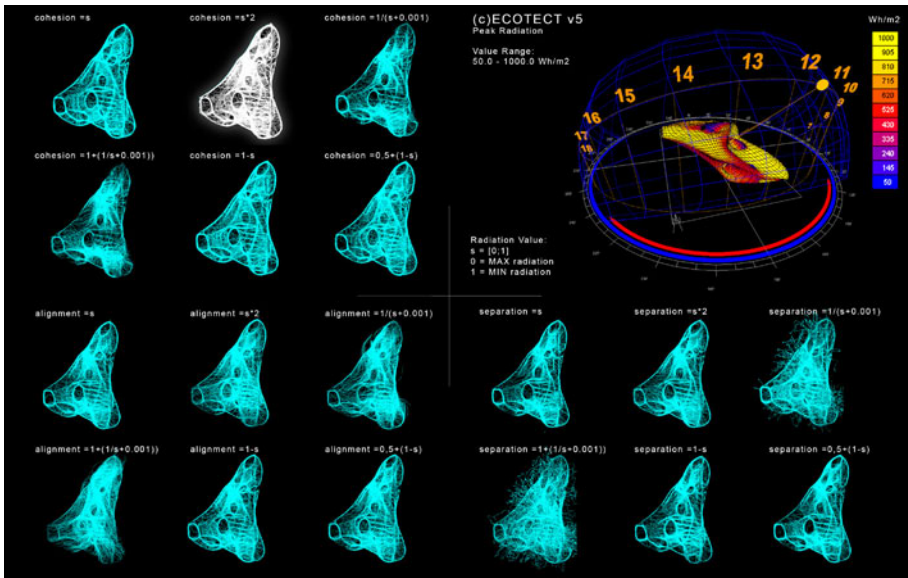


Fig. 3
Radiation-influenced agents' behavior on complex topology.

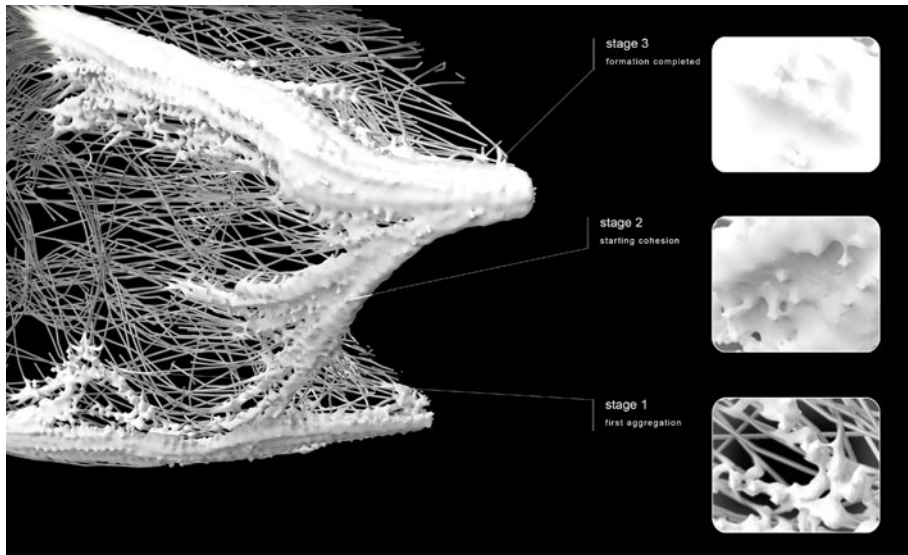


Fig. 4
Agents' construction behavior through progressive material deposition.

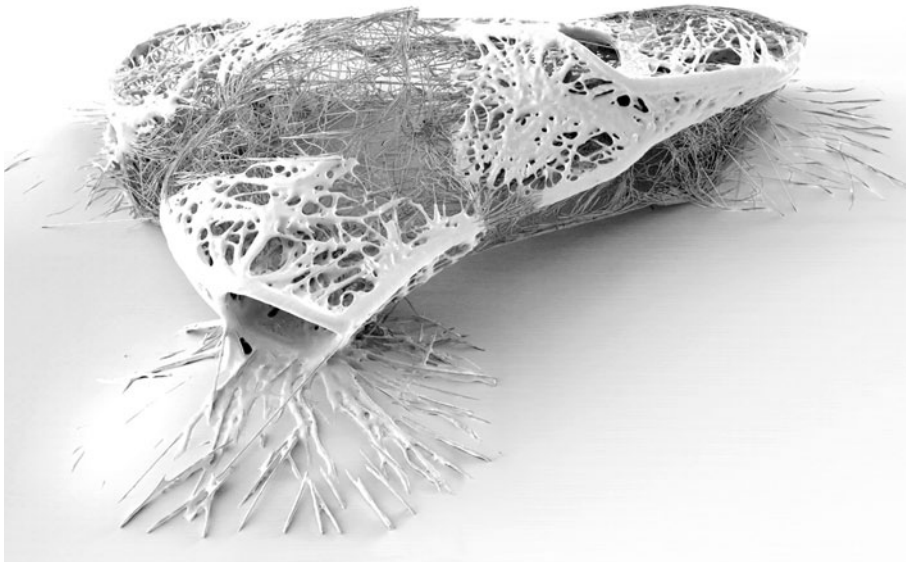


Fig. 5
Partially built structure with agents' trajectories.

tem); there is no pre-configured hierarchy of components, nor tessellation or subdivision. The variable density dictates the emergence of gradient conditions, from component-like sequences to full surface (Fig. 4, Fig. 5).

Emergent Reefs

The Emergent Reefs project thrives on the potential that emerges from a coherent utilization of the environment's inherent ecological structure for its own transformation and evolution, using an approach based on digitally simulated ecosystems and sparked by the possibilities and potential of large-scale 3D printing technology.

Coastal erosion is a process that, if uncontrasted, over time leads to seabed desertification and waterfront thinning, thus involving both marine environments and tourism activity. The intensified quantity of tourists in the last decades, while giving propulsion to the economy at the same time increased the sea-bed use and smoothing, thus easing the action of progressive erosion and homogenization of sea-bed condition. Much as the intensification of agriculture led to monocultures and the progressive disappearing of diversity, the intensification of coastal use is putting at stake marine biodiversity. Tourism cannot then be separated from environmental issues: it is a proactive vector of change acting within an ecosystem, causing regionally differentiated developments and transformations on different territories. Such transformations, often led by a prevalently economic self-sustaining push, are in most cases of two kinds: rapid developments of human infrastructures with heavy environmental impact, or strategies that consistently limit the economic potential in favor of the preservation of a static vision of the existing ecosystems. Steering clear from preservative strategies (which would limit tourism's inner potential by negatively impacting its economy benefits), tourism must be considered as a part of the ecosystem and a chance for its evolution and improvement. Not as a superficial or invasive overlay of functions and uses on a site neither as a nostalgic postulation of an idealized historical moment but rather a positive projection engendering new opportunities for the future. Rather than fetishizing flows of capital and production as a formal device, the project affirms this touristic mode through active intervention with material practices as a substrate to culture. The task then is not to resist the global push of tourism but to seek out the most creative ways to develop richer, differentiated regions within it. The possibilities of this work emerge from a coherent utilization of the inherent ecological structure for its own transformation and evolution. Considering tourism as internal to the ecosystem includes also evolved functional programs, morphogenetic strategies and production technologies as efficiently connected nodes of a coherent yet differentiated network. Instead of focusing on the solution of a specific problem (coastal erosion) through existing models and approaches, the intent of this project is to address the issue of a positive environmental transformation through the generation and construction of marine reefs shaped to host an underwater sculpture gallery while at the same time providing the material and spatial preconditions for the development of marine biodiversity on the transformed sea-bed. Starting from a digital simulation of a synthetic local ecosystem, a generative technique based on multi-agent systems and continuous cellular automata (put into practice from Alan Turing's theoretical premises¹³ through reaction-diffusion simulation) is implemented

in a voxel field at several scales giving the project a twofold quality: the implementation of reaction diffusion generative strategy within a non-isotropic 3-dimensional field and seamless integration with the fabrication system patented by D-Shape®. The entire project was developed with this specific fabrication process and technology in mind; such technology solidifies sand through liquid infiltration distributed via a custom built large-scale 3D-printing machine. Extending and scaling up the more common 3D-printing process, it uses the same additive tomographic layering strategy, with sequential layers of dolomitic sand upon which a row of nozzles drop a patented binder liquid only in the corresponding section points. The initial purpose of the invention was to print houses, however due to the several difficulties encountered during the development coupled with the necessity to financially backup the project, many different applications have been tried, mostly in the field of art (sculptures) and, more recently, marine barriers. Since objects to be produced can have a very heterogeneous generation history, a 3D voxel grid is used to rationalize them to the process and resolution of the machine. This step is not only necessary, it is the principle that links digital processes to the materiality, nonetheless applied in an extensive way: two different models of rationality are overlaid with a brute-force method, but one lacks geometry generation and the other misses the link to material production. Moreover, as a consequence of this double gap, since the resolution achievable at the moment is quite coarse (the technology is in constant development, so far vertical resolution - z direction, the layer thickness - is 5-10 mm and the liquid expansion causes a slightly larger horizontal xy resolution), the emerging pattern is mostly treated as an imperfection, considering the look of the digital model as a finalized result to tend to (Fig. 6).



Fig. 6

Large-scale 3D-printed building components with D-shape® technology.

Starting from these assumptions and in the intent of exploiting the expressive and tectonic potential of large-scale 3D printing technology, the project has been tackled exploring voxel-based generative strategies. Working with a discrete lattice eases the simulation of complex systems and processes (including non-linear simulations such as Computational Fluid-Dynamics) starting from local interactions using, for instance, algorithms based on cellular automata, which then can be translated directly to the physical production system. The purpose of Emergent Reefs is to establish, through computational design tools and strategies and machine-based fabrication, seamless relationships between three different aspects of the architectural process: generation, simulation and construction, which in the case of D-Shape® technology can be specified as guided growth. Additive fabrication strategies such as 3D printing have several advantages with respect to current technologies for reef restoration and design like Reef Balls®, or experimental precedents such as Biorock®: the possibility to embed intensive processes and real-time feedback in form generation without depending on modular unit-based construction (which allows the implementation of a greater specificity and a wider spectrum of heterogeneous spatial conditions, broadening design freedom); more specifically, D-Shape® design integration and material system (synthetic rock, not concrete) produces large-scale artifacts that allow the implementation of passive strategies for marine repopulation without continuous energy consumption.

The idea of an underwater exhibition architecture suggests a general layout articulated as a cluster of heterogeneous and connected halls. Such spatial distribution pattern is typical of a peculiar marine environment, the atoll. In order to generate a similar distribution pattern a strategy based on the interaction with a 3D data field (provided by the simulation of underwater currents) and attractors: in Complex Adaptive Systems, attractors are points in the space of possible configurations of a system (phase space) representing stable configurations, whether static or dynamic, towards which the system tends, generating stable, oscillating or propagative behaviors. Attractors are used in this simulation to represent the halls as stable configurations and let the system work to generate the intermediate states between them.

The adopted morphogenetic strategy for attractors consists of a virtual ecosystem: this bottom-up strategy is able to generate global configurations that are coherent with current behavior starting from simple internal local relations; global system coherence is then an emergent property of agents interactions in the ecosystem or, in other words, as the moment in which the global system reaches and maintains homeostasis. The simulation can be stopped manually when the ecosystem reaches a stationary condition (Fig. 7); in this case visual assessment is faster than and (for the required accuracy) as effective as coding a stopping condition; not to mention that such implementation, since it requires testing all agents in the system at each step, would have considerably slowed down the whole simulation. While the simulation is running it's also possible to tweak different parameters and alter or switch the agents' charges. During some of the simulations, closest packing behavior emerged despite no such specific code implementation existed.

The morphogenetic process itself is then developed through the implementation of a differentiation process that progressively separates void (passage) areas from those

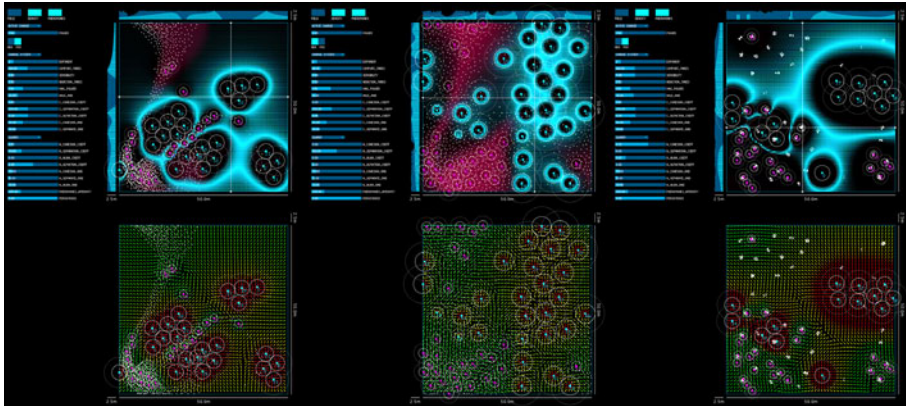


Fig. 7

Different fields layouts emerging from variations in agents' behavior.

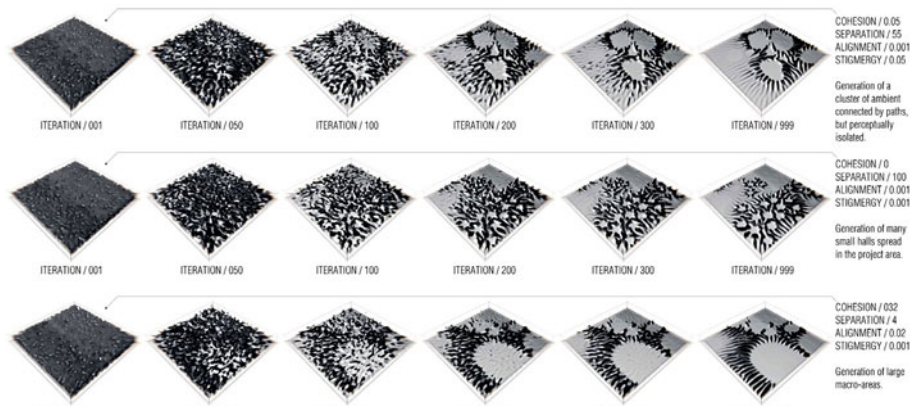


Fig. 8

Layouts generated with different ecosystem settings.

occupied by the material. In order to keep integral and coherent with the field generation and fabrication logic the exploration of cellular automata algorithms, focusing in particular on reaction-diffusion for its properties of condition-based differentiation and articulation in space, seemed an almost natural choice. As hypothesized by Alan Turing in "The Chemical Basis of Morphogenesis" such algorithms are the basis of morphogenetic differentiation, and can be simulated through a system of two interacting chemical substances, called morphogens, reacting together and diffusing in space or on a surface, generating differentiation patterns that can account for several processes such as brain growth and its spatial articulation or the pigmentation on animals skin. The reaction-diffusion process is implemented using Continuous Cellular Automata algorithms over the 3D voxel grid, which is the same underlying structure that allows a seamless transition through all the steps of the overall process, from analysis to fabrication. Voxels in the grid act like buckets where any kind of data relative to that sector of space can be stored.

The importance of anisotropy in patterns distribution arises from several necessities: avoid reef overturning, coordinate scuba divers trajectories and underwater currents with the reef formation itself in order to minimize human-reef collision chances and provide a distribution system of “corridors” connecting the halls. To achieve this, reefs are associated to the distribution-field of the morphogen v : the result is a cluster of halls surrounded by series of walls and paths aligned with underwater current vectors in order to reduce at once the reef’s overturning effect and the risk of scuba drivers being pushed against the generated walls. Through the simulation the reaction-diffusion algorithm a wide range of possible patterns emerge, associated to particular behavioral rules of the agents-systems (Fig. 8). Here are some examples of different system behaviors with their related distributions of underwater clustered halls.

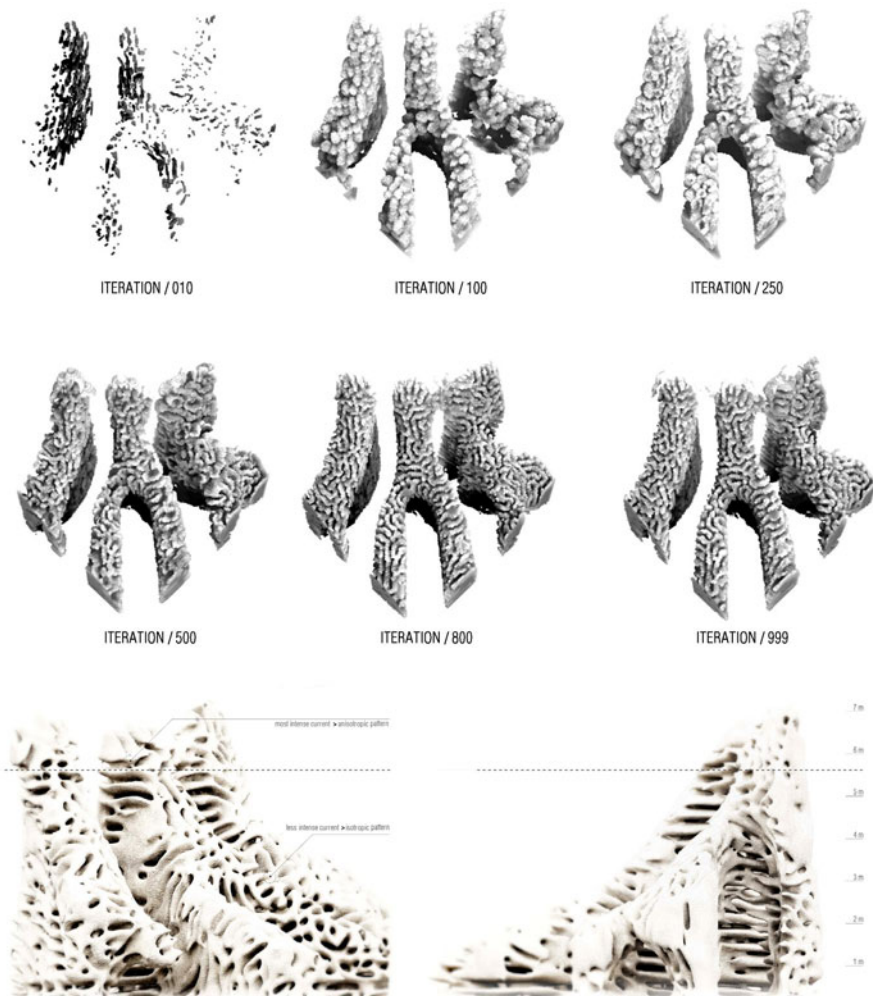


Fig. 9
Gray-Scott algorithm applied to a layout part.

By tweaking the simulation parameters it is possible to explore behavior variations within the system domain, achieving a gradient of possible distributions according to project requirements. The intent is to produce a broad range of heterogeneous spatial conditions in order to provide the largest set of opportunities for the local ecological community (this term refers to the complex food web that shares the same environment).

It is anyway necessary to endow the generated reefs with qualities present in the material substrate of other marine environments hosting a rich biodiversity, the most significant of which is the presence of cavities: they create a natural localized micro-gradient of resources and energies and are used as shelters by both weak and territorial fish species. The basic principle adopted is the same conditional void-matter separation based on reaction-diffusion algorithms: the aforementioned process is iterated at a finer scale in a self-similarity logic analogous to those exhibited by fractals. The result is a multi-layered domain, where every layer represents a particular field. In this model material system distribution, information and processes are all scalable: process is iterated with systemic yet heterogeneous results at different scales.

The project provides a material substrate for cultural development and aims to the possible repopulation of local sea-bed biodiversity by enhancing a pattern of differentiated spaces through the application of morphogenetic strategies that proactively shape the new environment interacting with its own physical characteristics.

Although some tests were carried on about the underwater behavior of D-Shape® material artifacts with positive results, no current testing can yet provide a reliable trend of its reactions dynamics over time (for instance, resistance to erosion), since large-scale 3D printing technology is still a breakthrough sector in an early development and rapid evolution stage and such kind of tests require a longer timespan to deliver trustworthy assessments. However this shouldn't be an excuse for limiting design speculations, while of course real constraints that can be found during further extensive testing should instead be considered and embedded in the project strategy. As continuous assessment and rapid adaptation are an intrinsic part of the design approach, further implementations are also foreseen (such as, for instance, material behavior and its influences in terms of weight, mechanical and viscous behaviors over time, erosion, etc.).

Projects credits

R+D - project developed by Pier Luigi Forte, Ilaria Fiorini, Giulia Bottura & Lorenzo Natali for a3 2012 Studio – 100YC at Università di Bologna.

find(&)merge - project developed by Andrea Barbieri, Filippo Conti, Giulia Mariotti & Beatrice Scardovi for a3 2012 Studio – 100YC at Università di Bologna.

Emergent Reefs – thesis projects by Alessandro Zomparelli as part of the work by Co-de-iT+disguincio&co for D-Shape®.

Notes

- 1 “Abstraction is a process by which higher concepts are derived from the usage and classification of literal (“real” or “concrete”) concepts, first principles, or other methods. [...] In computer science, abstraction is the process by which data and programs are defined with a representa-

tion similar in form to its meaning (semantics), while hiding away the implementation details. Abstraction tries to reduce and factor out details so that the programmer can focus on a few concepts at a time.” – see <http://en.wikipedia.org/wiki/Abstraction>.

- 2 “Representation is the use of signs that stand in for and take the place of something else. It is through representation that people organize the world and reality through the act of naming its elements. Signs are arranged in order to form semantic constructions and express relations.” See Mitchell, W. 1995, “Representation”, in F Lentricchia & T McLaughlin (eds), *Critical Terms for Literary Study*, 2nd edition, University of Chicago Press, Chicago.
“To represent is “to bring to mind by description,” also “to symbolize, to be the embodiment of;” from O.Fr. *repraesentare* (12c.), from L. *repraesentare*, from *re-*, intensive prefix, + *praesentare* “to present;” lit. “to place before”. A representation is a type of recording in which the sensory information about a physical object is described in a medium. The degree to which an artistic representation resembles the object it represents is a function of resolution and does not bear on the denotation of the word.” Resolution here is also related to the degree of abstraction, and “architectural” can be used in place of “artistic” – see [http://en.wikipedia.org/wiki/Representation_\(arts\)](http://en.wikipedia.org/wiki/Representation_(arts)).
- 3 in linear determinism correlation implies causation, or, in a different fashion, there is a clear and direct cause-effect relation. An experiment repeated n times with the same initial setup should bring to the same final state. Around 1950 Belousov and a few years later Zhabotinsky shook the former pillar of scientific thought with the discovery of chemical oscillators, thus opening the way to non-linear and far-from-equilibrium thermodynamics and, later, complexity theory. The common ground of contemporary thought is now well aware of emergence, non-linear dynamics and complex system in which a set of few, simple deterministic rules engenders a complex, non predictable outcome.
- 4 see Banks, J., Carson, J., Nelson, B., Nicol, D., *Discrete-Event System Simulation*. Prentice Hall (2001), p. 3.
- 5 see Wolfram, S., *A new Kind of Science*, Wolfram Media, 2002, p. 211.
- 6 A proactive behavior is anticipatory of events as opposed to an only reactive one. As for the speculative quality: “...from the perspective of human evolution, our great capacity is not just that we learn about the world. The thing that really makes us distinctive is that we can imagine other ways that the world could be. That’s really where our enormous evolutionary juice comes from.” Alison Gopnik (via fast-t-feasts).
- 7 see De Landa, M., *Deleuze and the use of Genetic Algorithm in architecture*, <http://www.cddc.vt.edu/host/delanda/pages/algorithm.htm>.
- 8 as John Archibald Wheeler prefigured and the theory on the structure of matter actually confirm – see It from bit theory - http://en.wikipedia.org/wiki/Digital_physics#Wheeler.27s_.22it_from_bit.22.
- 9 see Graham Harman’s Object Oriented Philosophy - http://en.wikipedia.org/wiki/Graham_Harman.
- 10 The ability to change and adapt behavior according to different contexts expressing systemic differentiation is also referred to as agency; more generally, agency refers to the capacity of making independent and autonomous choices.
- 11 “the architecture of information and the information of architecture via massive proliferation of biogenetic computing systems endowed with autonomous agency will revolutionize the world” - Karl S. Chu, Facebook status update, February 2012.
- 12 “in 1904, Charles Spearman, saw intelligence as a measure that can predict performance in multiple domains. In other words, consistency is key” – see Villarica, H. <http://healthland.time.com/2010/11/29/forget-iq-the-emerging-science-of-collective-intelligence-2/>.
- 13 see Turing, A. M. “The Chemical Basis of Morphogenesis.” *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 237, no. 641 (August 14, 1952): pp 37–72.

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**Designing and Scripting
the Seamless
and the Scaleless**

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**From analogue to digital,
to analogue, to...**

**The seamless process of monitoring,
understanding and affecting spatial
arrangements in a sensponsive
experiment called “Spirit|Ghost”**

Introduction

During the last ten years we witness a remarkable achievement in the field of architecture which is the implementation of kinetic systems in the built environment. While the exploration of this path is far from over, it is well established that as a feat it is feasible with a large number of interesting technologies already present. A plethora of novel experimentations and long-term research efforts have developed a variety of approaches, forming a technical know-how non-existent before. Yet, this quest brings us in front of a threshold. With the techniques to achieve *kinesis* conquered, what are the next essential elements that will ensure the wide acceptance of such approaches? Beyond the technical expertise lays the crucial aspect that defines the success, or failure, of any innovation: people's acceptance.

Innovation, in general, tries to permeate a resisting layer of inertia. In order for something radical or innovative to get accepted by the wider public, it must acquire certain characteristics that will facilitate a transition to a new (everyday) reality. Historically, humanity has crossed such a border many times, with the most dramatic one noted during the passage from the 19th to the 20th century. The contemporary pre-conceptions of the world were rocked to their core when many everyday life routines changed radically. While the changes occurring at the turn of our century may be dramatic as well, the broader information exchange and the innumerable predictions of the future to come make this transition easier. Nevertheless, though, the passage through the uncanny valley is there to cross, even if we make this journey while playing *Angry Birds* on our brand new smartphone.

Crossing the transitional phase

Examining the learning curve of three remarkable novelties of the 19th and the 20th century, the personal (domestic) machines, electricity and the telephone, we can identify three distinct steps or phases of transition in the process during which people accept an 'alien' object. The first phase can be described as *the establishment of contact*. Acquaintance with any novel element is crucial for the amount of time it requires to enter the next phase. The dangers occurring from design flaws in the first electric bulbs, for example, combined with bad wiring that often led to fires, made the acceptance path of electricity much longer than those of the telegraph before and the telephone that followed. The second phase in the described process is *relaxation*, in terms of putting one's guard down. This is evident when a substantial portion of society has accepted the novel element and incorporated it into everyday life.¹ This is the most important phase of transition mainly because it allows people to understand, from a 'safe' distance, the beneficial factor of the new technology. As distance is reduced and benefits become easier to observe, technology is perceived as 'friendlier' and the simple act of observation turns into familiarity. The third phase of the described process is pinpointed when familiarity turns into *knowledge*. This is the time when a large number of people not only accept the novelty but support its becoming a new tradition or status quo with mixed feelings of dependency and trust.

These are the three phases to identify during the transition of animated spaces from emergent novelties to applied facts in everyday life. Unquestionably, during the last

decade people have welcomed many models of automation in their life. A good example is the car. Many of its initial human-dependent features have been gradually replaced by indicators and switches, reaching the unimaginable in the past automation property described as 'cruise control.' We are currently approaching a huge threshold on that industry as well with the advancements made toward the autonomous car.² While it seems really hard to leave the wheel to an 'alien' entity, we have to admit that we have already taken a small step to that direction with automatic gearboxes. The only thing left is to pass the threshold of the first phase and enter the second, leaving fear behind as we welcome a new paradigm-shift.

A key element to this approach is manufacturing robots. Known 'ancestors' like Aibo and Asimo have already demonstrated that a robot's usefulness lies in the fact that it understands as much as it should regarding the context of the activity in the surrounding environment. Robots do their job well and as such they are accepted. This seems too rigidly utilitarian at a first glance but through an ecosystemic approach it is just a new thing fitting in. Robots managed to fit in because they had a simple job and they evolved just enough to do it well. Their low profile allows them to flourish and mutate, and continue to evolve to a higher tier. They opened up a niche of acceptance and this can only lead to more complicated and sophisticated variations, like Rodney Brooks' *Baxter*³.

Elaborating on the technical specifications that give robots basic contextual understanding, it is evident that their system is simple, or rather it seems to create a simple complexity. Their performance is also simply executed and while it appears amazingly complicated to see a 6-axis multi-performing robotic arm at work, its actual code is simpler than a lot of known game routines. The understanding capabilities of the manufacturing robots are limited because even though they have a lot of parameters to check and respond to (the complexity we perceive), they are all constricted in a certain area that defines the manufacturing line where the actions are numerically few. The predicted behavior also acts in their favor. We incorporate them into our lives, we feel at ease with them, and, above all, we know that we can shut them down.

In order to address a more complicated artificial environment, like a domesticated robotic entity embedded in architectural space, the challenge lies in easing its way through, not only for acceptance but mainly to unlock the full potential of its adaptation. Accepting the theory that raising the familiarity level is the crucial characteristic for wide acceptance, the underlying question is how to achieve it. There are five factors that must be taken into consideration toward this direction:

1. It must be a relatively known thing. This is facilitated by parallel applications that enjoy more exposure to the public.
2. It must maintain a relative low profile in its operation and act only when required.
3. It must be non-invasive, exhibiting mild reactions in order to be considered as non-aggressive. It must also be equipped with some level of control, like a log-off switch.
4. It must operate on a seamless process. In this way maintenance will be reduced as well as the effort given to operate.

5. Last, but most important of all, it must exhibit the ability of meaningful communication. This attribute will help it pass to the aforementioned third phase.

Based on the fact that responsiveness in space is well known, mainly through art installations, the abilities of some smartphones' application, and discussions around the coming autonomous cars, the first factor can be considered applied. The second and third are similar, although they refer to different fields of operation. Low profile refers to programming and behavioral patterns, while the mild reaction refers to the way the output systems work and perform their actions. Both of them, though, address the issue of continuous activity and its stressful effect on people. One can identify here the main difference that architecture has with art. Art is focused on a continuous action-reaction process, oriented to the ultimate goal that is to provoke emotions in the brief amount of the time experienced. Architecture, on the other hand, is experienced much longer, rendering a continuous vivid 'behavior' strenuous. The fourth factor refers to the system's assembly and the way it operates. Attaining a seamless process means that there is only one, easy to interact with, control interface. It also means that the device has the least possible number of individual parts and also that it mainly senses and actuates through the use of smart materials. The low operational effort in this case will have the same wide acceptance that the automatic gearbox had in cars.

The last factor reaches one step further into the future and it is the reason why this research direction is dubbed as *sensponsive*. If the embedded system exhibits sense in the way it understands and reacts, then it will gain people's trust more quickly, as a living creature would by adjusting its behavior and activity in relation to other creatures around it. Communication should not be elaborate but it must follow simple rules of *responding* according to a certain hierarchy and a crude knowledge-base for evaluating situations. The sensponsive logic involves the maximum application of the factors above in known responsive systems.

Identifying sensponsiveness

The path to a sensible spatial configuration passes through cognition. Applied cognitive skills are essential and the key element to achieve such a feature is time. The sensorial input of a responsive system comes from an array of chosen sensors, with their values triggering certain reactions. The system's reaction to input is immediate, as there is no time to process the signals further. New input re-adjusts those reactions in constant loops. An intelligent system, on the other hand, can exhibit a behavior in the way that it builds a knowledge-base and begins to identify activity patterns and their context. In this regard, a sensponsive system, compared to a responsive one, is able to choose the location and the type of the response, with time and timing being the most crucial factors in its operation. The difference between reaction and behavior lies in the fact that the immediate response should not be the only action, or the most important one, but just a part of a more elaborate process. This process formulates patterns over time that are understood as intentions and considered by the system as filters for reacting.

Communication, as an attribute, has the most potential for gaining people's trust. Ever since the rise and the swarm-like diffusion of personal media, space has been gradually dislocated in the human mind to become the background in people's activities. Through a *sensponsive* approach, space can elevate its importance by developing new human-centered features. First, it can become a medium that is able to connect personal media devices with the artificial environment in a larger scale. Second, it can become an active contributor to regulate the environment toward ad hoc conditions the users desire in an effortless way. A *sensponsive* system chooses where and how to act, thus contemporary issues of personal and social activities may be addressed more efficiently in the long run. When space starts acting in a way it makes sense, people's interaction with it will change as they will be surrounded by a more sensible environment. The goal is not the creation of genetic-forms or actuated architecture. The goal is not specificity. The goal is communication. The goal is connectivity. The goal is the emergence of a spatial consciousness. The drive is evolution.

Sensponsive architecture tries to describe an animated and evolving situation. It accepts its intermediate phase and tries to keep the profile low while delivering benefits. It passes through the hegemony of form and elevates performance. It seamlessly fits and follows, similarly to a simple organism that lacks complex cognitive abilities but retains a relative co-existence with its host by understanding the key factors that affect their symbiotic relationship and establishing a channel of communication.

The Spirit|Ghost project

Spirit|Ghost is an ongoing research project at the Laboratory for the creation of Transformable Architecture, Kinetic Systems and Intelligent Environments (TAKSIE Lab) in the Department of Architecture at the Technical University of Crete (TUC) that aims to create a *sensponsive* paradigm. The project uses as a targeted architectural setting the spatial arrangements and activities within an academic environment, following four distinct activities -lectures, study, workshops and unorganized, random activity. Spirit acts first by identifying the nature of human activities and by assessing how successful space is in hosting them, providing it that way with the element of sense. Spirit has a mission to comprehend, not to engage in a reaction. Spirit turns to Ghost when the system exhibits a high level of techno-spatial sophistication, manifests itself and people perceive its presence. This is the second phase where the goal is the creation of tools that can help designers attribute one more quality to space, behavior. In this phase, digitally-controlled mediators are integrated inside architectural elements, affecting space actively by changing the prevailing spatial and/or environmental conditions.

Theoretically the approach is grounded on a ubiquitous cultural tradition that acknowledges benevolent metaphysical entities dwelling in spaces, an act that the anthropologists generally refer to as *animism*. This provided the project with the psychological context in which people can react positively within a sentient changing environment, as well as with the theoretical framework to develop the human-computer interaction protocols. As a complete system it aims to:

- Form a seamless connection between design environments and smart assemblies that work in a constant loop.
- Establish the basic level of spatial attributes such as cognition, memory and personality that affect decision-making.
- Establish a spatial efficiency evaluation system.
- Support human activity spatially, physically and psychologically by taking informed decisions and acting on them.
- Create an 'actual' bond between people and their living space.

These goals can be achieved only through a human-centered approach in order to reduce the feeling of the uncanny and to provide patterns of human behavior in relation to space. These patterns can be analyzed to provide the critical parameters that must be monitored and addressed to achieve comfort and spatial efficiency. From there on, it is an issue of algorithmic design using tools from the broader area of artificial intelligence research. A crude diagram of how the system should operate is as follows:

input – analysis of input– activity/situation recognition – wait – input – analysis of input – verification of activity/situation or not – wait (repeat as required) – if yes then choose from one of possible good reactions programmed – if not start over (loop) – decide– activate (output) – wait – input – analyze input – estimate success of action– fine-tune as required or choose another reaction– wait – start over (loop)

The two key factors of the sense part is time for the system to understand and confirm a situation and an evolving database, produced through the machine learning process, in order to assess that situation and respond accordingly. The database can be educated through time and paradigm. Time can be handled through programming but the database must be set using spatial patterns, something that can be achieved through a virtual design environment. In our case, we chose Rhino to be this platform, since through Grasshopper and Firefly we are able to immediately establish the virtual-actual connection.

Project S/G 01

Our first working prototype is a basic, simplified model. The goal was to test the feasibility in principal of the whole system. We chose a simple geometry (a square), one parameter to monitor (crowd density), one spatial change (linear displacement of a partition), and a simple behavior (to increase available surface if overcrowding persists). We created two models, one virtual, on Grasshopper, and one real, equipped with sensors, Arduino controllers and motors. The 'bridge' between the two models is Firefly. The virtual model showed two limits, the actual and the dynamic one that followed the intensity of the parameter and inscribed the limits of the required space. The activity that took place on the real model informed the virtual one, and depending on the suggestions of the system, the limits of real space changed to accommodate the given situation until a new state of equilibrium was found through fine-tuning.



Fig. 1
 Snapshots of the virtual-actual bridge.

Project S/G 02

Our second working prototype is a more complex model, still though within an enclosed, defined space.

The goal was to develop an activity recognition system that would have the ability of verification. The success of this project was based on the minimum amount of factors we monitored to assess the type of activity within the given area. These are:

1. *Temperature*: Intensity and distribution in the given area
2. *Sound*: Volume, direction and distribution of sound in the given area
3. *Proxemics 1 (personal space)*: Personal spaces' radii can be zoned for more accuracy

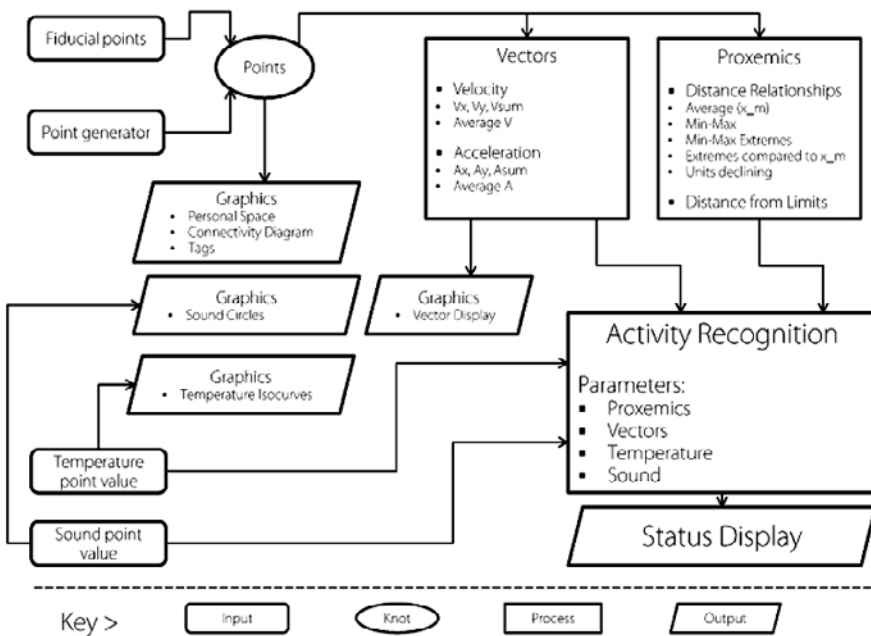


Fig. 2
 Spirit ("sense" process) flowchart.

4. *Proxemics 2 (people)*: Relative positions between people
5. *Positioning*: Position in relation to the limits of monitored space
6. *Analysis of movement in vectors*: Intensity, velocity and estimation of direction

Initially we worked with simulations. The amount of data received strained the system, and demanded the work to be distributed. After a successful row of simulations, we proceeded with building a special setting where we tested the results. The linked working environments are *Rhino – Grasshopper – Firefly – Actual Interactive Setting*. The latter is comprised of a gridded surface that is monitored by photocells, microphones, and a webcam. A projector is used to show the overlapping of the two models and test the fidelity. Fiducial markers act as people for the image recognition via *reactIVision*. The system is now capable of recognizing four types of activities typical within an academic environment: lecture, study, workshop and social contact (as unorganized activity).

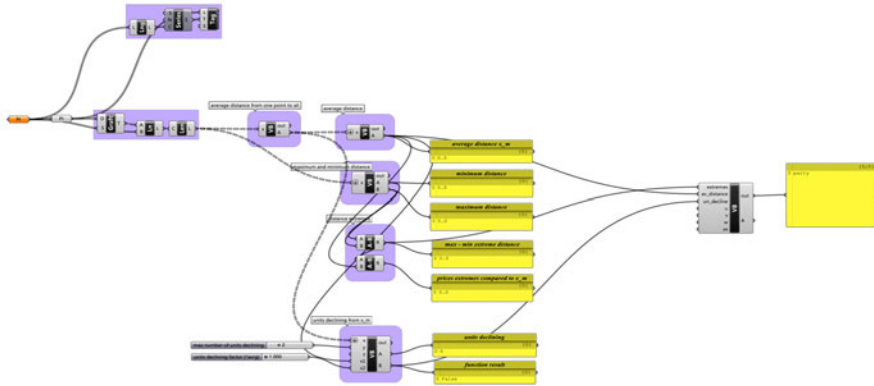


Fig. 3
Grasshopper definition for Pattern Recognition.

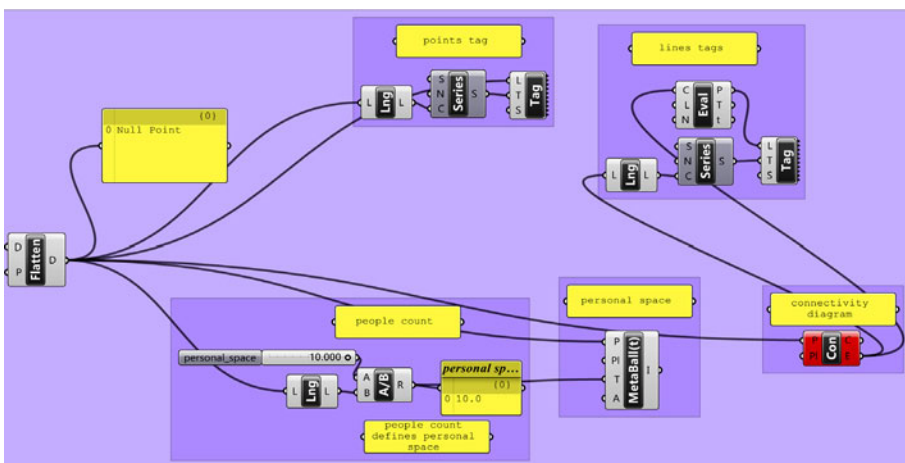


Fig. 4
Grasshopper definition for Personal Space Radii.

```

1 Option Strict Off
2 Option Explicit On
3
4 /**
5 Imports<System.Runtime.CompilerServices.CompilerGenerated()> _
36 Public Class Script_Instance
37 Implements IGH_ScriptInstance
38
39 Members
40
41 Utility functions
42
43 /**
85 Private Sub RunScript(ByVal x As List(Of Object), ByVal y As Object, ByVal z As Object, ByVal x1
86
87 Dim xexwra As New list (Of Integer)
88 Dim i As Integer
89 Dim v As Integer = 0
90 Dim avrg As Integer = x1
91 For i = 0 To x.Count() - 1
92 If x(i) > (x2 * avrg) Then
93 xexwra.add(v)
94 v = v + 1
95 End If
96 Next
97 If xexwra.count() <= y And xexwra.count <> 0 Then
98 B = True
99 Else
100 B = False
101 End If
102 A = xexwra.count()
103
104
105 End Sub
106
107 '<Custom additional code>
108
109 '</Custom additional code>
110
111 End Class

```

Fig. 5
Segment from VB scripting.

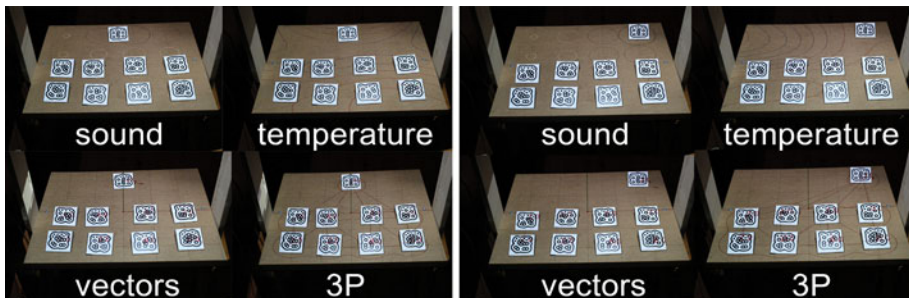


Fig. 6
Snapshots of two time frames dT1 and dT2.

Conclusions

The S/G 01 and /G 02 projects achieved the two first aims toward a complete *sensponsive* system by establishing a basic level of cognitive skills to the system and by achieving a reciprocal relationship through Rhino – Grasshopper – Firefly – Arduino – Actual Spatial Conditions in a continuous loop. Since Grasshopper is not meant to perform

loops, a certain amount of tweaking was necessary to achieve the tasks. Therefore, a more stable platform is required. Having the feeling that we outstretched our ability as architects, we have extended our research to include computer engineers to address this issue as well as the feasibility of the next projects we are working on currently, which deal with the development of a more complex cognitive model in an open space scenario, the evaluation algorithms, and a decision making/reaction generator, based on the work of Paraschos, Spanoudakis, Lagoudakis on robotics and artificial intelligence⁴. In general, the development of probabilistic models of programming for making assessments is required as an add-on for design platforms, perhaps like a 'black box' operator where we feed the values from the sensors in real-time and provide the assessment gradually informing the design tools or the controllers.

For these goals to be achieved there are five steps to be followed in order to create a complete system. These steps are describing the different systems that need to be integrated in space and in turn create the whole. The loop of the process also has a validating and testing purpose. The principals of this can be implemented in simple or complicated systems, depending on the number of parameters, the hardware required, the types of software to connect and the time required for programming. The steps are:

1. *Data collection and management.* It includes the hardware for sensing and the initial processing of information on a format that can be used for the coming logical operations. The visualization of the data in a design environment starts from this point. It is crucial to mention here that the system is non-intrusive, eliminating monitoring techniques that can give hints regarding the identity of people.
2. *Recognition.* Through the development of Machine Learning Algorithms that identify certain patterns, the system recognizes and verifies types of activities taking place in the monitored space.
3. *Evaluation of spatial efficiency.* In this step, the system evaluates the spatial efficiency according to given values within a given range described as 'ideal zone' where people have an augmented perceptive experience. In this step, the system reveals the programmed intention and starts to act with 'sense'.
4. *Responding.* The system estimates possible responses and simulates them in a design environment to be better understood. Through argumentation processes it reaches a choice that is presented to the administrator.
5. *Fine-tuning.* The system is in a constant fine-tuning process following the changes of the type and the characteristics of the activity as they develop. The system continues to learn how to improve its decision-making abilities.

The broader scope of this experiment is to identify the critical parameters according to use. These parameters are either related to recognizing people's activities or affecting the experience of people according to activity types. These parameters will be used to set 'archetypes' for the combination of space-activity relations that will be evolved and diversified through time from the system in order to accommodate different 'styles' of architecture. It is also aiming in the creation of new tools, such as the development of Machine Learning algorithms, through the combination of supervised and reinforcement learning methods and algorithms for State Estimation, Deci-

sion Making under Uncertainty, as well as Context-based Decision Making⁵. The notion of space as an interface is another goal, essential to the integration of IT systems in an architectural context. As the project progresses, we expect the following:

- The creation of a functional, stable and efficient real-time bridge between virtual and actual space.
- The identification of the least possible parameters that can provide enough data for accurate estimation of activity types and characteristics. Until now research findings have narrowed them down to six regarding positioning, movement dynamics, sound and temperature.
- The development of an efficient system for reading the conditions (and the 'situation' as it happens) within a space.
- The development of state-of-the-art algorithms regarding system learning from a complex situation, as human activity is, and understanding its context.
- The development of state-of-the-art algorithms regarding decision making in a complex situation.
- The increase of the communicative abilities of space with people that will be able to facilitate a participatory design process.

We are currently working on the sensponsive systems in full-scale models. The Spirit/Ghost projects must perform in an actual setting so that they can be properly evaluated. We have reached a level of advancement in implementing technology in architectural settings where prediction and projected potential is not enough. Working prototypes where people can actual live for a time will give the catalytic information to formulate viable solutions that will gain wide acceptance from society and lead to widespread applications. So, after programmers helped so much the evolution of architecture, it is the time for roboticists to provide their assistance in a massive way, from sharing the recognition and cognition models they use to the development of equipment and machinery that can perform in multiple ways in an architectural application. Close collaboration with other disciplines always brought a fresh change and it becomes growingly necessary for achieving the next logical step.

Notes

- 1 Gladwell, M., *The Tipping Point: How Little Things Can Make a Big Difference*, New York, NY: Back Bay Books, 2002
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- 3 <http://www.rethinkrobotics.com/index.php/products/how-baxter-is-different/> (retrieved 02.10.2012)
- 4 Paraschos, A., Spanoudakis, N., and Lagoudakis, M., "Model-Driven Behavior Specification for Robotic Teams", in *Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems (AAMAS)*, Valencia, Spain, 2012.
- 5 Chalkiadakis, G., Boutilier, C., "Bayesian Reinforcement Learning for Coalition Formation under Uncertainty", in *Proceedings of the 3rd International Conference on Autonomous Agents and Multiagent Systems (AAMAS-2004)*, New York, NY, 2004, pp.1090-1097.

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Porous Ascend



Fig. 1
Conceptual model in 3D plaster print.

Introduction

The point of departure for the research is the problem of complexity in relation to the creation of the schema by which we arrange the parts of an architectural object. In order to gain overview, when subjected to complexity, a common solution is to proceed by structuring a design into hierarchical and interlinked subsystems¹. Though, by thinking hierarchically we often choose to position elements with reference to an extrinsic coordinization; as seen with the use of the modernist grid, as well as the ubiquitous arrays of elements within many projects departing from parametric models. Here overview increases but we might not be able to explore the best possible way of interfacing with a context unfolding in a less orderly way at several different scales simultaneously². This is precisely why the possibility to operate by means of more complex principles of organization is an interest of the research.

The described research proposes that within a digital design practice the necessity to follow a regular, extrinsic coordinization and to separate elements by scale are no longer present. By utilizing algorithmic, generative methods we can establish an approach to positioning and establishing relations between elements within a structure that is locally determined. That is, where elements are not identified and shaped according to a global reference but to locally situated information. It is possible to do so because the use of computer programming, within design, allows us to externalize the overview of the complexity attached to the formation of a structure from the designer³.

With this outset the aim of the project was to look for an organizational principle that could test this idea of a design that continuously unfolds from local points at different scales, and to explore such a principle at the level of design, production, assembly and material behaviour.

Research/Project Context

The research was conducted within the framework of a PhD study investigating the utilization of generative computational processes as a means to organize component

based architectural constructions, and how these processes can be used to question the need for a hierarchical organization of a design space.

The final physical demonstrator, described below, was commissioned for a public event showcasing research investigating digital modelling and production technology within architecture. A limited timeframe, economy and requirements attached to clearly communicating the project to a broad audience were decisive for the choice of realizing the system as a tower, as well as the amount of elements, choice of material and included parameters.

The title, *Porous Ascend*, refers both to the visual appearance of the final demonstrator and the idea that the concept of porosity in a sense addresses the topic of interface and connectivity above. The concept of porosity is a term denoting a measure of the void spaces in a material. It relates to a notion of relative scale between components of a material. Where porosity is high, the difference between scales of individual components is small. Low porosity, on the other hand, requires a significant variation in sizes to fill the space enclosed by the material. In the context of the project *porosity* figuratively speaking becomes a measure of connectivity.

The Pattern

As a starting point for the research, and in order to create the desired situation for the distribution of elements, an underlying conceptual pattern was invented (Fig. 2). This pattern brings together two geometric concepts: *recursion* and the aperiodic *Penrose tiling*. These are of interest because each one possesses a property of the sought after principle, and in combining them a formal situation arises, where the organizational situation of interest can be explored.

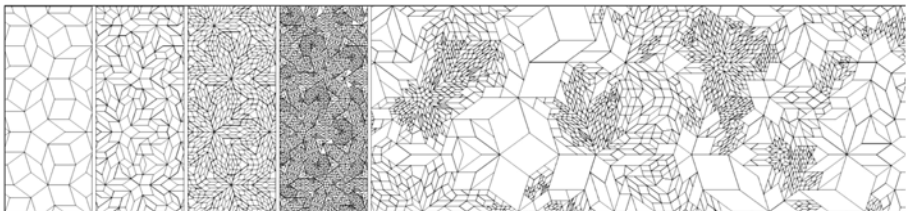


Fig. 2

The penrose tiling combined with recursion.

In mathematics recursion is the act of defining an object in terms of that object itself⁴, in computer science this becomes a function written in such a way that it calls itself from within; when the idea is applied to geometry a shape acts as placeholder for the drawing of similar shapes, often as scaled versions of the original⁵. Fractal geometry is naturally recursive. This type of geometry represents a flatness whose singularity lies in its ability to maintain an extraordinary but constant level of complexity at every scale. Sanford Kwinter formulates it thus: “A fractal object is complicated because it contains the principle and rule of its being at every point; it contains an infinity of stages and cycles, and, instead of occupying new unitary dimensions, it inhabits the infinitely variable space between dimensions.”⁶ In a sense we are presented with a seamlessness of scale, which is the item that is of interest for the research.

Regarding the Penrose tiling⁷ [Penrose 1974], the property that is of interest here, is its inability to exchange one section of the tiling with another. That is, it is an ever changing pattern. This occurs because it is generated through operations of symmetry rather than translations. The result is a situation where, even though the individual rhombic figures of the tiling repeat, the neighbourhoods, into which they fit, does not.

The idea behind the pattern developed for the project was to apply geometric recursion to this ever-changing pattern, so as to supply its continuous unfold with the ability to act at different scales, in a fashion where shifts in scale occur instantaneously without the use of gradient transitions in the geometry. This was inspired by previous projects utilizing recursion but who departed from a hexagonal pattern^{8,9}.

In order to utilize this pattern an appropriate design tool was needed by which a design process could unfold. The overall criteria for this was to be able to interface with the generation of the pattern, utilize it as a spatial structure and to unfold this structure for production. It was decided to write this from scratch, i.e. outside the scope of an existing software package. Firstly, because of computational speed limitations attached to creating the recursion in a 3D software package. Secondly, because the dialogue between designer and structure required the development of a customized user interface.

The Tool

The bespoke design tool was written using the Processing language (Java). It is divided into a 3D viewport and a graphical user interface (GUI) (Fig. 3).

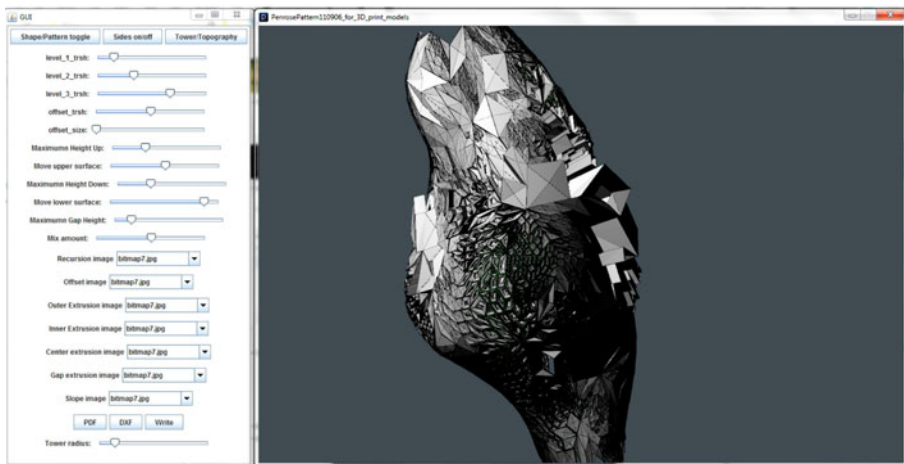


Fig. 3

The bespoke design tool developed for the project.

Through the GUI the user has access to a series of sliders and buttons that makes it possible to manipulate the design; e.g. amount of recursion, extrusion, curvature and positions of openings. A principal technique for defining variables within the design is here the ability to link 2D grey tone images as placeholders for 2D arrays of information. This means that where the manipulation of single numerical values is not

meaningful, interfacing occurs through images. Here values are extracted by reading the grey tone levels of the image at a position extracted from coordinates within the structure being designed. As an example, at the level of the underlying 2D pattern such an image is used to decide where the pattern performs recursion and for how many levels (Fig. 4).

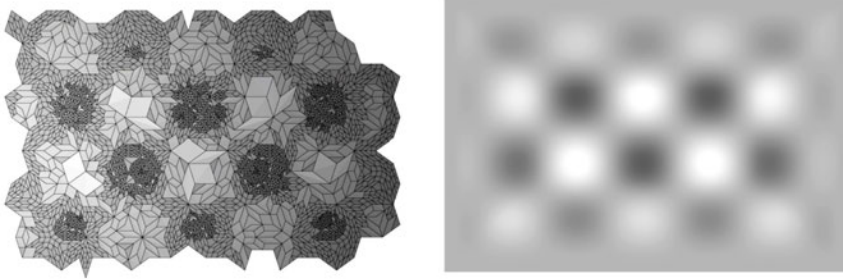


Fig. 4
2D Pattern and corresponding grey tone image.

Turning the 2D pattern into a 3D structure can be performed in two different ways: Either as a *'landscape'* where 3D elements are extruded upwards from the pattern (allowing for overview of the curvature of the overall surface), or as a *'tower'* where elements are extruded outwards from a cylinder that the pattern has been wrapped around. The reason for doing so is that the cylinder presents a generic base for the tower shape, that allows a bottom-up behaviour of the elements to define the design's overall shape, while keeping to this category of structure.

The individual 3D elements are shaped by connecting the end and start point of the extruded edges to the extruded centre point of the rhomb; drawing a triangular surface. This was done for both back and front side.

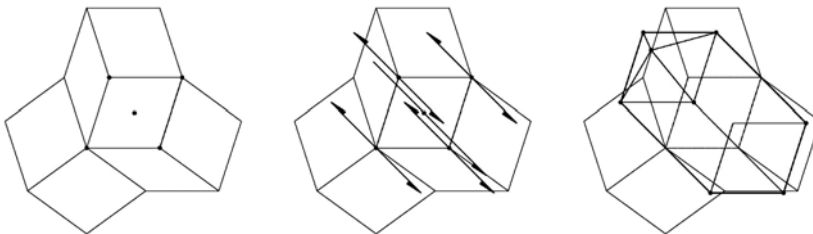


Fig. 5
Extrusion of single element from the 2D pattern.

As with the amount of recursion the shapes of the individual 3D elements were also informed by interfacing with grey tone images. Here the variables controlled were:

- (i) Extrusion of elements from the 2D pattern: This was done for both front and back of elements relative to the 2D pattern.

- (ii) The amount of sloping as opposed to a stepwise extrusion: This made it possible to create transitions between a fluid and a crystalline formal expression.
 - (iii) The position of the centre point described by the triangles forming the front and back of an element: That is, varying whether the expression of the element was concave or convex.
 - (iv) Opening up and closing off of elements: This made it possible to create transitions between elements being frames as well as solids.
 - (v) The amount of offset between elements: Making it possible to have gaps within the structure.
 - (vi) Controlling the height of an imagined frame within the offset.
- (Variables (iv) - (vi) were not included in the final demonstrator due to time and cost constraints.)

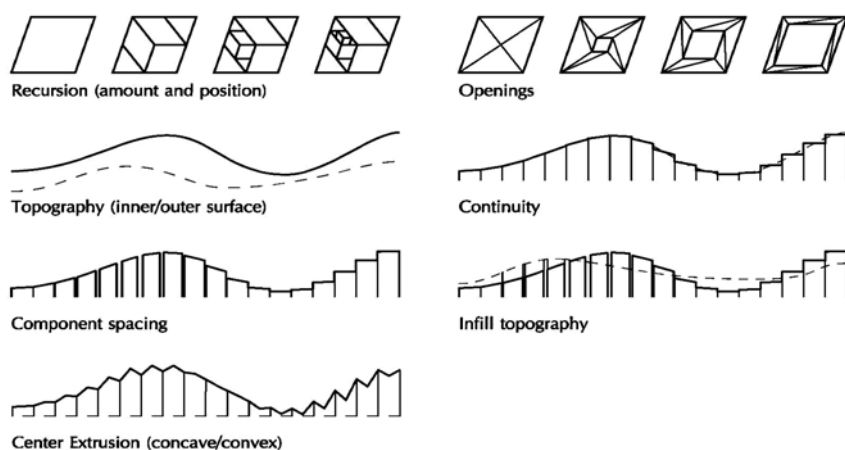


Fig. 6
Design space parameters producing the structure.

The Making

The aim of the development of the tool described above was to be able to create designs that could be realized as physical models demonstrating that the system could in fact be build. For this specific purpose the idea was to unfold each individual element and produce them in CNC cut cardboard.

Preparing the data

The most challenging problem in dealing with a variably recursive pattern lies in the fact that there exist no pre-defined coordinization mapping the position of elements. This means that indexes are given relative to where and when they are drawn. Position is locally, not globally, defined. This means, in effect, that the indexes of neighbours to an element need to be extracted as an additional operation after generating the structure. Getting the indexes of neighbours to an element is the only way

to identify where in the structure an element is situated and therefore impossible to build without.

The technique applied to this problem was to subdivide the edges of each element according to its level of recursion. This was necessary because large elements would potentially have more neighbours than small ones. For each subdivision an algorithm was applied to search the population of elements for coinciding edges. When a coinciding edge was found, the index of the element it belonged too could be extracted and attached to the edge searching for neighbours. By following this procedure for all elements, all edges and all subdivisions of edges it was possible to map the connectivity of the entire population of elements.

Unfolding for production and building

The unfolding of the elements forming the structure was also done as a stand-alone application. The challenges attached to developing this tool was:

- (i) To avoid writing a universal unfolders by deciding the best strategy for unfolding the specific elements within the project.
- (ii) To deal with the problem of material tolerances and thickness

Regarding the strategy for unfolding the individual elements, it was assumed that efficiency would be compromised if unfolding was done in the most appropriate way relative to each individual element. This would have meant that the geometric configuration of each unfolded element would not always be the same. In this case the folding process would have been slowed down by requiring an interpretation of the unfolding strategy creating the piece. Instead a strategy was devised where approximately 95% of the elements could be unfolded in the same way¹⁰. The remaining 5% required a slight manual redraw to avoid self-intersecting geometry.

Material tolerances and thickness were also a challenge. In order to accommodate for imprecisions occurring from both folding the material and the thickness of the material itself all unfolded elements were reduced in size according to measurements gained from prototyping in 1:1

Additionally it was necessary to attach information visually to the sides of all elements regarding neighbours. This meant the index of the correct neighbour, as well as the contour of the side of this neighbour. This last feature was necessary because elements would often be extruded in steps relative to each other, i.e. neighbouring elements were often not connected at the corners, but somewhere along the surface of a side.

Production

The unfolded elements (Fig. 7) were collected in a CAD file and nested to fit cardboard sheets of 1 x 2 meters. This sheet size was decisive for the maximum size of element, since it was unfavourable to divide an unfolded element into two pieces.

Different colours were used to divide lines into cutting, folding and drawing paths. The last type was needed for getting the information regarding neighbours mentioned above onto the cardboard.

The cutting was done using a CNC knife-cutter producing 527 individual elements.



Fig. 7
Unfolded elements.

Building

The actual building (Fig. 8) of the structure proceeded by first folding all elements and sorting them in numerical groups for better overview. A 2D map representing the position and numbering of elements was produced to keep track of the assembly process. From here sections of the tower were identified and assembled into larger fragments, these were again brought together to form the actual tower.

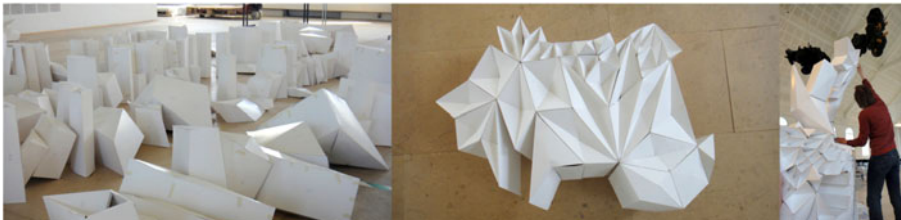


Fig. 8
Folded and sorted elements, an assembled section and the attaching of a section to the overall structure.

Findings

The final structure (Fig. 9) stood approximately 4.8 meters tall, when all 527 elements had been folded and connected according to the production drawings. The process of developing the project from concept to physical demonstrator offered important insights into the challenges of building digital tools, material knowledge and the organization of parts within a build structure.

Making digital tools

Regarding the decision to develop the project through a bespoke tool, independent from a 3D modelling software, a number of conclusions could be made. At the level of user interface, starting from scratch allowed the GUI to depart from the specific situation of the project, rather than a general purpose tool-set. Additionally recursion rapidly challenges computer speed and early testing in Rhinoceros and Generative Components proved very time consuming compared to the results achieved with Processing. However, where computer speed was not an important factor, e.g. in the case the unfolding of elements, it would seem that parametric modelling could have been used with advantage. Saving time due to easy access to geometric transformations and drawing tools.



Fig. 9

The final physical demonstrator.

Material Knowledge

An important experience gained from the experiment regarded the difficulties of dealing with material tolerances. This was especially attached to the realization that it is disadvantageous not to operate with a space between elements. Even though digital modelling allows an extreme precision within the digital design space, this precision is always met with the necessary imprecision of material reality. Material thickness, properties and handling all add up to produce a situation where we can never assume the kind of exactness offered by the purely digital. Therefore it was concluded that future experiments would need to operate with a space in-between elements, either as void or material difference. This space would offer the possibility of equalising the unavoidable deviations from the expected.

An interesting material property resulting directly from the use of recursion was also observed. In areas with high amounts of recursion it could be detected that structural strength followed. In this way the utilization of recursion as the basis of an architectural structure points towards a potential for a distribution of strength relative to locally defined needs.

Organization

The project proved that we can design and build structures with a complex organizational principle through the means of digital tools. The potential benefit to this is that

it allows a greater variety in the ways architecture interface with an outside. Variety in structure seems to point towards a more reactive and adaptive architecture. Though, in order to implement a system with the complexity of the described project, within a concrete building, future research into efficient planning of the building process and site is needed. When we move outside the scope of the digitally controlled model we naturally lose its ability to keep track of the overview. A proposal for future research could in this connection be to develop digital monitoring techniques for complex assemblage extending the scope of the digital.

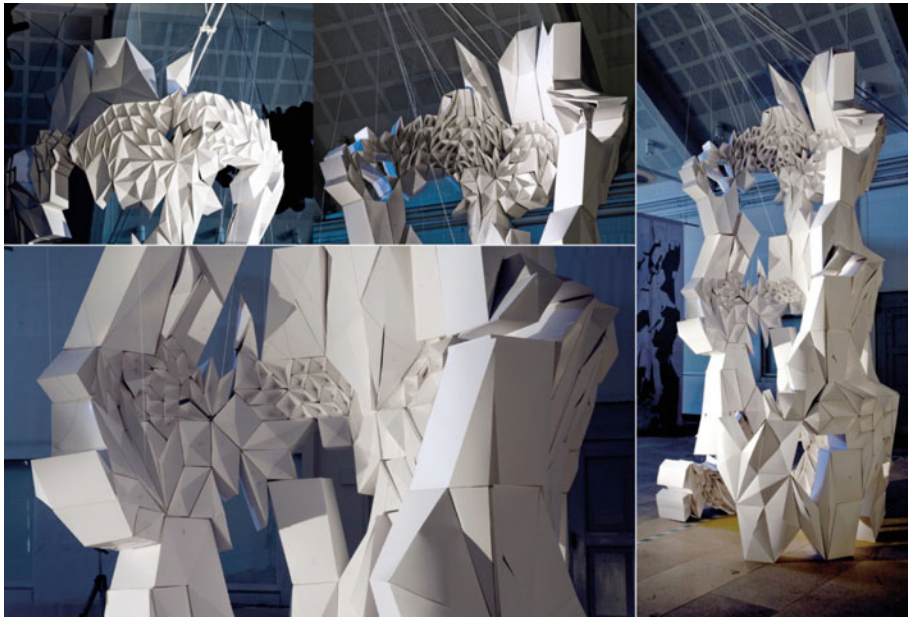


Fig. 10
The final physical demonstrator.

Acknowledgments

The project would not have been possible without the help of Annica Ekdahl in both the design and production phase. Gratitude should also be addressed to Quantum Sails for sponsoring CNC cutting and Tutein & Koch for sponsoring materials. Lastly, a big 'thank you' to colleagues and students at the Royal Danish Academy of Fine Arts for help with the building and folding.

Notes

- 1 E.g. Alexander, C. *Notes on the Synthesis of Form*, Harvard University Press. 1964.
- 2 Gibson, W.J. *The Ecological Approach to Visual Perception*, Psychology Press.1986, p. 9.
- 3 Terzidis, K. 2006. *Algorithmic Architecture*, Architectural Press. 2006.
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- 6 Kwinter, S. *Architectures of Time*, MIT Press. 2001, pp. 129-130.
- 7 Penrose, R. "The Role of Aesthetics in Pure and Applied Mathematical Research", in: *Bulletin of the Institute of Mathematics and Its Applications*, Vol. 10. 1974, pp. 266-71.
- 8 Aranda, B. Lasch, C. *PIN-UP magazine*, Issue 4. 2008.
- 9 Tamke, M. Thomsen, M.R. "Implementing Digital Crafting: developing it's a SMALL world", in: *Proceedings of the conference Design Modelling Symposium*. 2009, pp. 321-329.
- 10 The strategy was as follows: The first triangle making up the top of an element gets re-drawn in 2D by measuring lengths of, and angles between, segments. Subsequent triangles forming the top gets redrawn in 2D in the same way, and rotated so as to connect to the previously drawn triangle in the order that they are drawn in 3D.
From each of the triangles forming the top part of an element its corresponding side is drawn, also by using lengths and angles measured in 3D. In connection to the first of these sides the bottom part of a triangle is placed, drawn in the same way as the top piece, but with the first triangle rotated so as to fit the end of the side-polygon.
Should it turn out that the unfolded sides are intersecting, this strategy is repeated starting from the next triangle forming the top part of the element.

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Integrative Design Methods in Architecture

**An agent-based modelling tool
for integrative design**

Introduction

The perception of the architect as a creator of the built environment has changed a lot over the last decades. The architect is no longer only the “creator”, the figure that decides following an ideology or an artistic direction, he has become a part of the building process strongly interacting with its other parts (engineers, contractors, constructors). His purpose is to propose maximum efficiency and the most economic option for a design task. Thus the building process does no longer start with the architects “view” and end with the constructors realizing it, the purpose is to create a design that somehow fulfils the criteria posed by all participants. In order to achieve this desired efficiency and performance the whole design process has to be questioned.

Building is an increasingly complex process, in which many different factors interact. Using today's technology makes it easier and easier to control this complexity, but the design process itself needs to be adapted to these options and complexity. Having a big number of participants in a building process requires an integrated process in which as many factors as possible can interact in order to increase the performance of the built object. The architect is more of a mediator of these interacting parts and needs to develop a process in which the correct communication, input, processing of information and response, is possible.

Research Context

Design Methods and Optimization

Generally the design task may be defined as a search for a solution to a multitude of design problems and given facts. The difference in the design method is set by the chosen aspects to which the design responds, by the order in which these aspects are worked through and by a multitude of subjective factors that differ from designer to designer. Besides the subjective factors and the personal input of the designers that lead to unique solutions, the way in which all set criteria are worked through and transformed into a solution may vary substantially, even without the designer consciously choosing a certain design method. This can be partially compared to an optimization procedure in which the solution tries to satisfy as best as possible the huge amount of input parameters, of course depending on the designer's working method.

While a mathematical optimization method cannot be simply applied to a design problem, given the enormous amount of constraints and optimization factors, it may still be useful to have a closer look at a number of optimization methods. When trying to find a design methodology that integrates as many factors as possible from the beginning of the process, a multi-criterial optimization method should at least be considered as part of this process, especially since the amount of data cannot be processed by the human brain alone.

Many heuristic optimization methods use the computational power of today's machines to produce a big number of alternatives that are then analysed. While this approach may lead to satisfying results, the aim of this research was to search for an option in which the design system itself constantly evolves and can be approached by the user at

any moment. Thus one option, evolving, should be a more fitting method than a “black-box” in which a huge number of options is created and evaluated and the user can only see and interact with a final result. The system should be constantly changing, trying to reach a maximum optimization to the chosen criteria, but still be open to input or disturbance from the user at any moment. This type of process should satisfy a designer who often wants to have maximum control of the process, rather than a “machine” that offers one final solution that the designer cannot fully comprehend.

Addressing the discussed parameters of a design problem may result into different design strategies. The question usually is, how and in which order the designer is going to process the big number of factors and constraints that a design problem poses. So far there are two well defined strategies used in the design practice, the top-down strategy and the bottom-up strategy (Palnitkar S. -“Verilog Hdl - A Guide to Digital Design and Synthesis”). In order to clarify the different strategies, the example of a gridshell roof structure will be used throughout the paper. If we majorly simplify the construction of such a structure to 3 parts that exemplarily define the different systems and scales of the structures, we will choose the global form as one major component, the division of this shape as another and the panels used for closing the structure as a third one. These three components range from a global shape to a singular panel and thus represent the different scale systems in which a design process should take place. All three of them should be in a relationship to the others and be developed according to the properties of the other ones.

If we take a closer look at the Top-Down approach that has been used in design practice for many centuries the different design factors or systems will be successively worked through and have impact on the ones following. Thus a first chosen criteria, often the global shape of a building, will first be set, constraining the solution of the next criteria to what satisfies this first chosen one. Each design criteria is consequently worked through, decreasing the solution space and number of viable options with each step. Often, after choosing a first criteria the next ones will only be problems emerging from the first set definition that need to be solved in order to achieve a working solution. This strategy may often lead to very early compromises, all depending on the first move, or even to “dead ends”, forcing the designer to start all over with a totally new or changed first solution. While this method successfully reduces the number of options and factors to be considered, it also neglects a huge number of viable solutions from the very first step and creates a number of new problems that might have been avoided with a different approach. In the chosen gridshell example this method would first define a rather randomly chosen global shape and then try to find a valuable method of division and a panelization. Many freeform shapes may not be able to be panelised with the desired element, for example planar quads or hexagons, or may not result in a working division. The Top-Down strategy has been used for many years in design problems but proves its limitations especially in the way architects, engineers and manufacturers communicate today. Often these three parts work successively on a design problem. The architect defines the shape, the engineer has to find a solution for the structure of this shape and the manufacturer has to find a solution for the proposed structure and shape. The latter two have to solve problems that might have been avoided if they were integrated in the first stage of the design.

A Bottom-Up approach defines itself by choosing not a global shape, but a basic principle, part or property that will then lead to the global design. This basic part is analysed, abstracted or processed, so that it may sum up to a global result, hierarchically higher than the chosen part. By carefully analysing and defining the characteristics and limits of the basic part a global shape can emerge that already takes into consideration the problems that would develop from the chosen principle. This way the design has avoided a certain set of problems by carefully analysing and taking into account one central characteristic. In practice this could for example mean that the architect takes into account the size, geometric characteristics and behaviour of the manufacturers defined part, of which the global shape will be built. Through an assembly logic or other principles the global shape emerges without the designer knowing from the beginning how it will look like. This approach is often used in contact with bionic principles or assembly logics and already serves as a solution for a set number of problems that a Top-Down approach sets.

Still, the goal of the proposed research is to expand this bottom-up principle to a design strategy that doesn't just choose one basic principle, usually the smallest part, but tries to integrate as many different parts and principles in one single process, so that all parts are processed simultaneously and may inform each other at the same time. While the contained systems may differ in their hierarchical order, they are to be treated equally and simultaneously, thus enabling a lower hierarchical level system to inform a higher one and the other way round. The process in which this information exchange takes change still needs to define a central part with which it works, but this part has no higher importance than the other participating systems. In order to achieve this, an appropriate method has to be found with which designing a grid-shell structure using all information of its systems and subsystems is possible (Fig. 1).

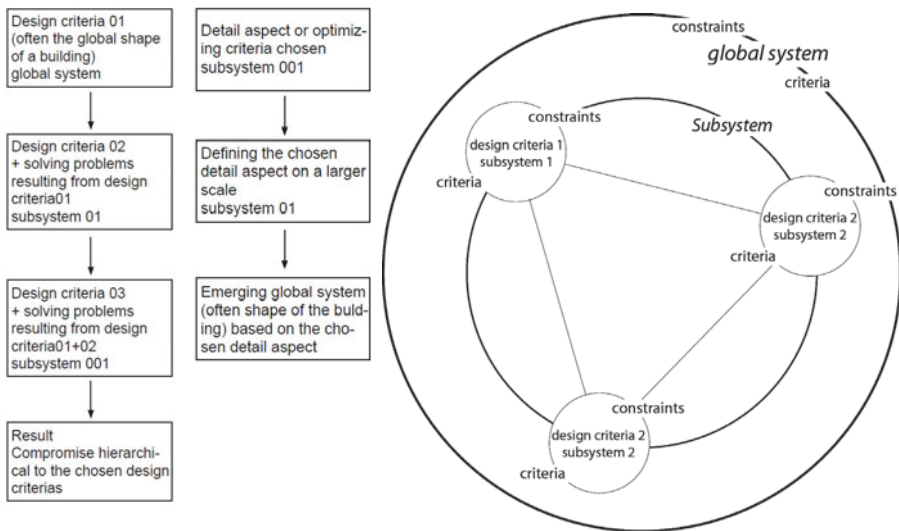


Fig. 1
Top-down, bottom-up and integrative design diagrams.

Bionic Principles – self-organization and agent systems

Bionic principles have proved to be useful in the search for appropriate optimization techniques or even in new design-methods (Knippers J., Speck T. "Design and construction principles in nature and architecture", *Bioinspiration & Biomimetics* Volume 7, 2012) (Knippers J., Gabler M., La Magna R., Waimer F., Menges A., Reichert S., Schwinn T. – "From Nature To Fabrication: Biomimetic Design. Principles For the Production of Complex Spatial Structures") (Menges, A. – "Biomimetic Design Processes in Architecture: Morphogenetic and evolutionary computational Design", *Bioinspiration and Biomimetics*, Vol. 7 No. 1.). Nature consists of a stable complex adaptive system in which each part interacts with its connected parts and continuously evolves. Even though the pursued optimum might not be the desired one in an architectural design attempt, the way in which nature's systems and subsystems are in a continuous communication with each other and constantly influence every other system provides a perfect example of an integrative process. Hence a closer look at nature's organizational systems was the natural next step in the search for an appropriate design method.

The basis for all natural formations, whether living organisms or non-living formations is the principle of self-organization. Self-organization can be described as a process in which the organization of a global system increases constantly without having a central source that provides this organization. Research has shown that all natural systems and formations, even the more complex ones, rely on the principle of self-organization, of small parts that follow simple rules and that generate complex behaviour through interaction (Camazine S., Deneubourg J., Franks N., Sneyd J., Theraulaz G., Bonabeau E. - "Self Organization in Biological Systems") (Ashby W. R. - "Principles of the self-organizing System").

For living organisms this principle is often observed in swarm-like behaviour. Swarms or flocks function without a central control entity and still complete complex behaviour. If we watch the characteristics of a bird flock or fish school we notice that the whole swarm seems to follow a central rule. Actually each part of the swarm follows a set of very simple rules that only concern its immediate neighbours, or the ones in a defined range. Through reacting to the state of the neighbours following basic rules, the whole swarm functions as one entity and evolves in complex behaviour. Ant colonies use this method for finding food for the whole colony, bird flocks to avoid obstacles and danger. Human behaviour also follows swarm rules, especially in crowd behaviour. The main focus of the swarm theories is that through a set of given basic rules for each agent, a much more complex behaviour may evolve for the complete system (Eberhart R., Shi Y., Kennedy J. - "Swarm Intelligence") (Resnick M. – "Turtles, Termites, and Traffic Jams: Explorations in Massively Parallel Microworlds").

J.H. Holland defines complex adaptive systems as the principles on which the natural system is built (Holland J. H., "Hidden Order - How Adaption builds Complexity"). These systems all follow simple rules and describe all sorts of systems that we encounter in living nature. As previously described for agent-based-systems, the participating parts of a global system, in this case the living natural surroundings all follow a

given set of basic rules in order to function. The simple following of rules does not necessarily lead to a growing fitness of the organism or the global natural system, it's the capacity of these parts to adapt that leads to a constantly changing system. Adaption requires the participating parts to receive and react to information from other systems. Thus each of these parts receives processes and emits a certain set of information, meanwhile changing its state. Through conscious and unconscious learning these systems evolve over time to increase their chances of survival. Thus complexity first emerges through the interaction of all systems involved in a process. (Holland J. H. – "Emergence. From Chaos to Order").

Considering this rule-based behaviour that appears in all natural systems, allowing each part of a system to receive and process information from any other part of a system, thus helping the entire system evolve into a more optimised state, these principles may lead to a valid base for an integrated design method. If each subsystem and its part is able to receive information from all the other participating systems, and react to it in such way that the global system evolves, a continuous information flow is assured enabling to process a number of information of a number of subsystems at the same time.

These systems have been used in several research areas from cybernetics to economies, but little research has been done on how we might apply these principles to design and architecture. While many design methods rely on bionic principles the focus of this research won't be a defined bionic principle but the try to implement certain aspects of natural systems in order to create a basis for an integrated design strategy.

Agent systems have been used in architecture and design especially for simulating behaviour and less for designing itself. We find agent-systems in crowd-simulation tools (Karunakaran A. - "Organisation of Pedestrian Movements: An Agent-based Approach") (Bruton D., Kunkhet A. - "Grammatical Design and Crowd Behaviour: A Study of Factors that Influence Human Movement in Urban Spaces"), (Bandini S., Manzoni S., and Vizzari G. - "Crowd Modeling and Simulation - Towards 3D Visualization"), (Aschwanden G., Halatsch J., Schmitt G. - "Crowd Simulation for Urban Planning") or tools that use the human moving behaviour as design inputs. Other design-related research uses agent-systems for analyzing and instrumentalising information flow for creating design concepts (Beetz J., Van Leeuwen J., and De Vries B. - "Towards a Multi Agent System for the Support of Collaborative Design - Assembling a Toolbox for the creation of a Proof of Concept"). Others implement self-organization and agent-systems for very precise design tasks (Kanellos A., Hanna S. - "Using a Particle-Spring System to Generate Structural Space-Filling Lattices"). The further approach of this research will be to use the principles of agent-based-systems in order to generate a tool to create the foundation for a complete integrative design process.

Research in the field of integrative design methods has been ongoing for many years, trying to implement e.g. fabrication characteristics into the design process or material properties (Hensel M., Menges A. Weinstock M. - "Techniques and Technologies in Morphogenetic Design", Architectural Design Vol. 76 no 2) (Menges, A. - "Material Computation – Higher Integration in Morphogenetic Design", Architectural Design

Vol. 82, no.2) (Hauschild M., Karzel R. - "Digital Processes"). The difficulty now lies in connecting a higher number of factors and systems in this integrative process, especially parts of different hierarchical systems, without setting one primary leading part or particularity.

Research Goal

The purpose is to use self-organising systems, such as agent-systems in order to connect the different systems of different scales in an architectural approach, so that these might inform each other and be addressed simultaneously and not successively. Thus a design process is created that allows every part of the system to influence the other ones.

An agent-based system is for this purpose the best procedure to be implemented, since it allows its parts to add a number of basic rules, interact with each other and create a complex outcome through this interaction. Optimization or improvement methods can always be simply added to the agent's behaviour through a new rule, thus this system is open for further development. It also does not compute a great number of alternatives; it follows one solution that is changed and optimised through every iteration of the algorithm. It would then allow, in a further development, interaction between the user and the process since it is not a closed, "black-box" process, but one that can be followed and that can react to new inputs at any time.

Implementation

In order to present the concrete implementation of the chosen agent-system, the previously described gridshell model and its defining subsystems (global shape, division, panels) is going to be used. The purpose is to create a global functioning tool that can be further developed and expanded, so the simplest type of division was chosen, a triangulation. In a further development a different division or a combination of panel types may be added, but for the first part the triangulation was easiest to be controlled. For the panelling option a prototypic shading element, as simple as possible, consisting of a tetrahedron with two closed and two open faces was chosen in order to show how a panelling component may react to other influences.

The starting constraints were the area to be covered by the structure, three pre-set support locations and a set of obstacle objects that defined the space which the structure was not supposed to enter. From these boundary conditions the system was supposed to find together and create a closed surface that may roof the given area.

Through object-oriented-programming a self-written tool was created that was able to simulate an agent based system. This was divided into two separate stages, the first in which the agents are defined and their basic rules are set so that they find together and the second in which additional rules were added so that the global system seeks to optimise for certain exterior criteria. In the first development stage, the agents were defined as the smallest part of the system, a triangular panel, and received rules that enabled them to connect to each other in order to create a surface. Constraining the

number of agents that connect at a knot (between 5 and 7) and through attraction and rejection forces it was possible to avoid the problem of a too complex and not smooth spatial arrangement of the triangular panels. A smooth surface was created that connected the three support locations and did respect the set obstacle space.

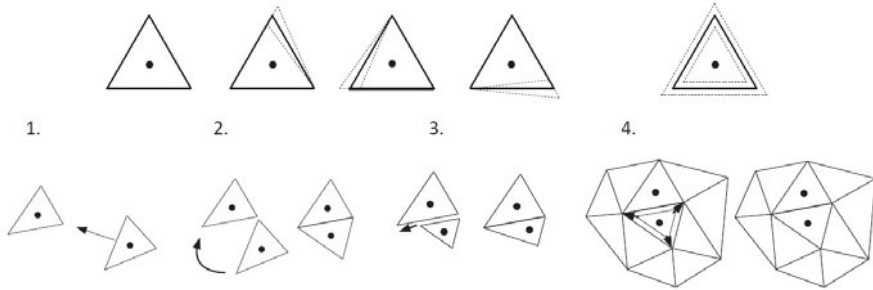


Fig. 2
Triangular agents.

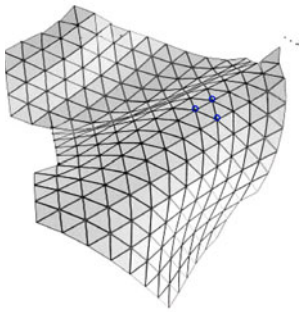


Fig. 2
Generated surface.

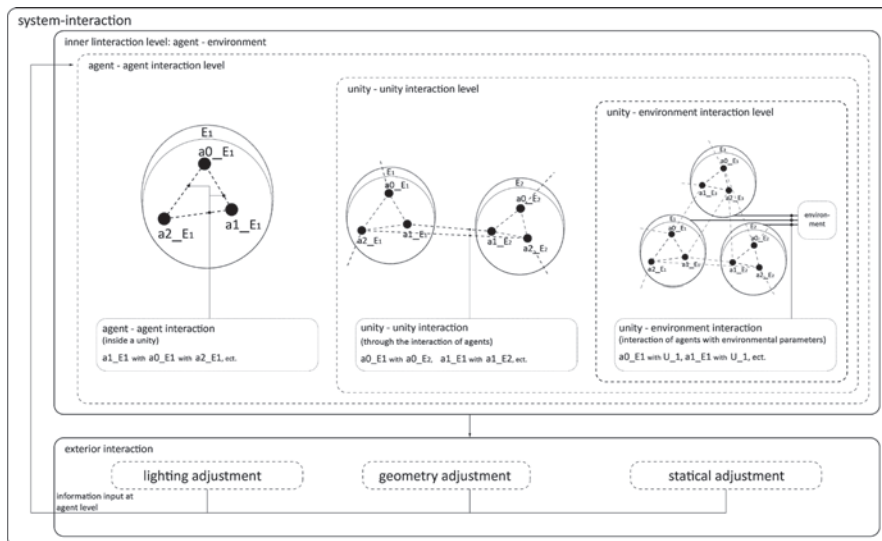


Fig. 4
Agent interaction diagram.

In the second phase additional rules were defined that enabled the system to improve for certain chosen criteria. These included rules for keeping the length of the beams as similar as possible, a geometrical static optimisation, a lighting/shadowing optimisation and a connection to Sofistik for a static analysis and so an improvement of the whole system. All of these rules were properties that were added to the agents, that can be indefinitely extended to add to the agents' behaviour.

Case study / results

The definition and initialization of the generation process is made through the selection of boundary conditions and definition of specific criteria plus the selection of different system adaption possibilities. Boundary condition in this case is the urbanistic situation where the agents have to interact, the borders, obstacles and support locations, in order to find a solution. The chosen urbanistic situation is exemplary; the agent-system would perform in the same way in any other kind of situation.

Start scenario 1:

It is defined that all support points of the chosen start support location have to be occupied by entities before the generation of the freeform surface begins. By the selection of a start support location one can predefine the supporting direction of the system. Still, this definition is against the idea of emergent agent system where connections are being made by interactions of the systems elements (agents) itself and are not predefined in any way (Fig. 6).

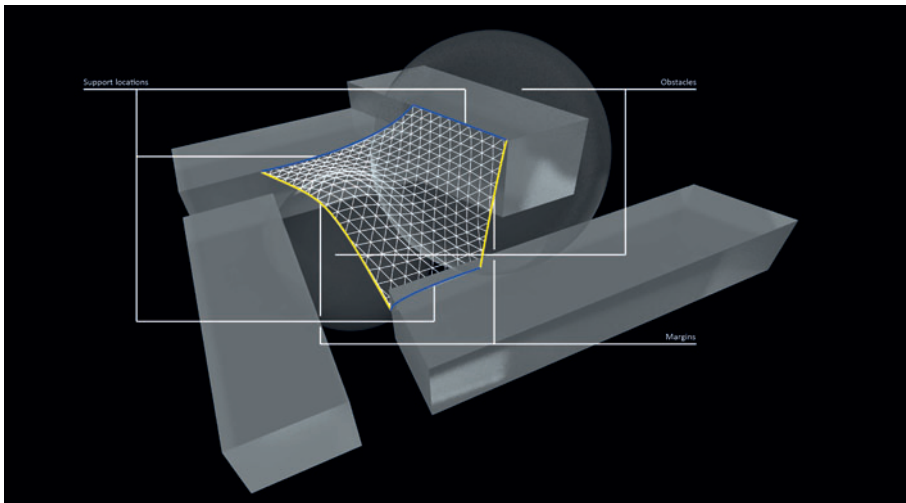


Fig. 5
Boundary conditions.

Start scenario 2:

The entities start connecting with each other where they are created. Through the fact that each entity's agent has a random velocity and direction in the beginning, the occurring geometry floats unexpectedly through space before it meets borders, obstacles and support locations. If this kind of generation process is started again, the result will be totally different, resulting from the fact that random direction and velocity vectors in the beginning of the simulation will never be the same twice (Fig. 6).

There is a wide range of creation possibilities by different behaviour combinations. The results will differ according to the combination that has been made before the start of the generating process. First the kind of start scenario, second the behaviour when the systems meets borders and support location and third the additional agent behaviour, lighting adaption, geometry adaption and the interaction with structural analysing software.

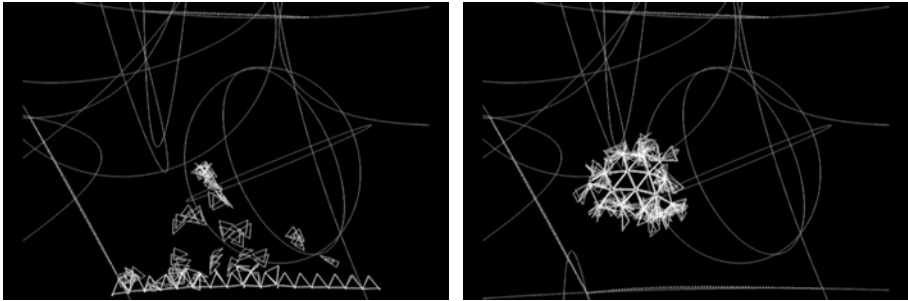


Fig. 6
Starting scenarios.

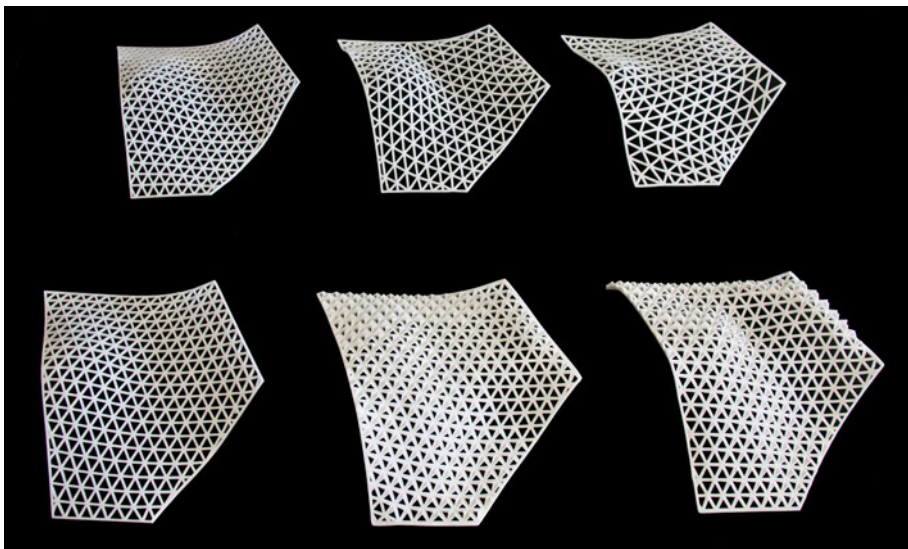


Fig. 7
Resulting surfaces.

Self-organization without any kind of system adaption (geometry, light or analysing software) creates a surface geometry that only satisfies the given boundary conditions and specific criteria. Through the geometric adaption agent behaviour the minimal and maximal turning points in the created geometries have been increased for more three dimensional curvature in order to transfer load free of moments and thus have better material utilization. The lighting adaption adjusts the developing surface and the geometry of the shading panel to a given light vector, where the surface's porosity is being maximized at 100% shading to the given vector. Through a structural analysing software interaction loop the developing surface is statically evaluated at certain states and, if necessary, goes through an extra optimization loop. Through all these adaption methods the created tool can be adjusted to the desired criteria and further developed in order to fulfil much more optimization criteria.

Conclusion / Outlook

After analysing the conventional top down design process for freeform surfaces a different strategy was developed: an integrated design process in which the constituent parts interact on the same hierarchical level in order to create the system. This strategy was embedded on the basis of agent systems into a digital design tool. Right now this tool works with entities of three agents. Further research would include extension of entity types from three to four or more agents (triangle to quad) or even a combination between these types. Furthermore the interaction between the user and the programmed tool should be analysed and included in a future development. Other factors to be improved are the optimisation methods that can be indefinitely extended to create a more complete design tool. The proposed tool is supposed to be the basis for a modular tool that is open for extension and at this stage only represents the possibilities of an integrated design tool.

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No Scale, i.e. Full Scale

Introduction / aero-photography

Scale, materiality and closing are three qualities difficult to find in the digital code. The code inserts a rather scale-less approach, conveys an immaterial and intangible perception and remains open at all costs. Understanding these three qualities as an opportunity and at the same time as a limitation, we designed an annual fourth-year design studio course, to deal with them and to propose an intermingling of digital and analogue manners that can be enriching and mould-breaking.

The course deals with the coexistence of a theoretical and a practical approach as well as with the combination of digital and analogue technologies, investigating upon the way that new qualities, or better still, new forms of pre-existing qualities can surface from the coexistence and fusion of digital and analogue concepts. During the course, boundaries, dipoles, and limitations are questioned in order to achieve a holistic, all-inclusive, comprehension of architecture which allows links and interrelations rather than specializations and segmentations.

Concepts¹ / scale-less sketches

Scale is a conceptual tool that is being questioned in the digital age. In the past, scaled representations and models have been used to achieve comprehension and control. In the analogue age, *scale* has been an important tool for architectural practice, a tool not referring to sizes but rather to the relations among the parts; to the relations among parts and whole; and, finally, to relations with the human body². The automatic interpretation of scale, in hardcopy architectural representations, an outcome of significant experience, made possible the direct reference to the human body. Digital code annuls scale as parts are no longer dependant of the whole and as the code refuses to acknowledge other systems of reference than itself. Digital code questions even the distinction of parts and whole, as all remain interchangeable and open to further manipulation. Passing from one scale to another – a signifying process for the traditional phases of architectural work – has been abolished as the process is now open, continuous, indefinite and endless. There are no more predefined phases as those enunciated by the use of different scales in the past. Scale was not only used as a practical and useful tool but furthermore it was a method that permitted conceptualizing representations and reductions of the project. Reduction is understood not merely as lessening, degradation, diminution but also as simplification, abstraction and idealization³. Even in cases where scale was not used in the context of a linear approach, this was an act of breaking the rule. The digital context entails a different procedure; the file constitutes one entity, from the first line to the final line, making possible for the first sketch to share the same digital space as the detailed final project. These models without scale are models with no front and rear part, that can do anything, rotate, extend, change size and are only momentarily crystallized in interchangeable scales. Consequently, the corporeity of the architect is questioned – as scale existed as a mediator between body and project; the hand knew how to slide through the lines mimicking feet moving about in real space. Digital code refers parts to each other, to the code itself and not to exterior references. Between the architect and the project there is only a mediated relation through the code and this is an ex-

tremely conditioning mediation. In the incorporeal and immaterial dominance of the code, scale, eminently linked to our body has lost its sense.

Materiality is another important issue as digital code can be very suitable for representing materiality but in an oblique, peculiar way, as its essence is based in immateriality. The essence of the code is based in immateriality and intangibility and therefore digital representations are quite different than analogue ones where the hand seems omnipresent. There is a certain preference for the eye in the digital code rather than the hand and tactility is not always present. For architecture this is an important issue as final architectural objects are not destined to the eye but to the hand, the touch, or, better still, to the synaesthetic perception of the whole body. The *hand*, used in the past as an instrument of vision, in order to achieve the completion of the perception of appearances, is also an acting agent: grasps, creates, and sometimes it can be said to think⁴. Even when the hand is present, thanks to evolutionary interfaces, its trace is immaterial, open, scale-less. The eye is now re-educated so as to be able to work like the hand, but in order to do so, the eye has to seek its emancipation from the brain and gain the animalism of the hand. However, architectural representations are used in order to represent an object that doesn't exist, an object projected thanks to the virtual construction possible by the combination of abstract parts. These representations become far more accurate and exact in the digital era; the computer re-interprets the distance between representations of the architectural object and the actual architectural object. It then becomes possible to have immaterial digital tools that permit the design and approach of architectural projects not through the combination of infinite reductions, abstractions and representations, but rather in a direct and immediate way, as a three-dimensional object that is capable of generating an infinite number of representations of itself⁵. Of course, the digitally designed object can seek its way to production in a simple, immediate and continuous process that questions the gap, created in the past, between design and production. In a strange and contradictory way, the immateriality of the digital code now makes possible a new closeness between architect and architecture. Constructability is immediately linked to computability, opening new opportunities and questions⁶.

Openness is another important characteristic brought on by the digital code in the context of architectural design. The indefinite manipulations – the possibility to cut, copy, paste, alter, move, detach, stretch, erase, and finally undo or redo any operation – the lack of limitation to the number of operations – the paper had limits inscribed in its materiality – the elimination of trace of what has been – the palimpsest is now visible only to the code - and the existence of indeterminate phases and transitions are all decisive factors allowing architectural designs to become more and more self-sufficient and at times even, self-indulgent. Architects have, of course, always felt a certain attraction for their media, but digital technologies allow a new type of seduction and furthermore a new kind of comprehension of these model-worlds that appear now at the same time as operational models and as autonomous, self-serving, worlds. In the digital formation of architecture – the architecture that has previously been formulated through means of reductions and models – constructed architecture becomes more and more a surplus and not a *sine qua non*. The openness of the code can, at times, seduce young architects in ways that constructed architecture seems to

fail mainly because of its heaviness, its inertia, its irrevocability and its sense of ending. The architectural object is, by definition, built, finished, closed for the architect and therefore independent and self-sufficient from its creator, it has a life of its own and a death prescribed in its materiality among other factors. Digital representations are always open, never finalized or cut off from the architect's control, virtual, possible and multiple, a dynamic potential, which remains indefinitely open⁷.

Design/ 1:500

The change of paradigm that digital technologies entail is reflected in the ways architecture is taught. This paper deals with the three concepts presented, i.e. scale-lessness, immateriality and openness in relation to architectural education. The combination of digital tools and analogue practices, allowing a fusion of specific qualities from each technology, in the context of architectural education is a deliberate aim. It seems important to allow and maintain the possibility of combination and of belonging to both systems. Translators – dealing with the re-interpretation of one system to the other – are especially fortunate because they obtain exteriority and thus liberty from the restrictions and stereotypes of each idiom in the perception of the world⁸. This educational approach is adopted in order to allow focus, at first, on the concept, the abstract reference, and gradually on the process towards the end-product of architecture, the materialised concept - the architectural object.

Currently spanning its third year running, the annual fourth-year design studio course, *"le mur est dur"*^{9,10}, nowadays *WallLab*¹¹, taught at the School of Architecture, D. U. Thrace, seeks to engage students in a dialogue on architecture through the medium of analogue and digital technology (also acting as tutor during the first year of the course: E. Mandoulidou). Students use digital and analogue tools, exploring their possibilities and limitations. The virtual, scale-less, space of the World Wide Web is the vehicle utilized for exchanging ideas, information, concepts, and designs both inside and outside the studio, extending the "real", "actual" educational space offered at the school's facilities, at the same time lifting the common normative preconceptions in the production of architecture – i.e., the linear evolution from larger to smaller scales. The actual construction of a limited number of projects, which become materialized architectural objects, comprises the final phase of the studio.

Special emphasis is put on the function of the student body as a community. During the preliminary phases of the course, students are asked to interact - comment on the projects of each other and the blog is used as an open-ended system that aims to inform and to instigate communication among the group. The blog also forms the platform for communication in the "actual" class. Students bear in mind that during the second semester they will have to operate as parts of large groups, therefore having an honest interest in participating in the projects of others. The big groups formed in the second semester often pose a challenge as they become difficult to manage requiring a certain hierarchy to be established among and by the students. They work in subgroups responsible for specific aspects of the fabrication and they are asked to go far beyond the detailed final design, getting in touch with providers and purchasing materials, dealing with contractors for work they cannot do them-

selves and also communicating to local authorities in order to be able to install their work in public spaces.

Analysing the concept of the studio course and following the evolution of realised projects that culminated from it, the remainder of this paper is structured in three parts; section 4 focuses on the topic, aims and structure of the annual studio course. Section 5 follows the evolution of specific concepts into their realisation, while section 6 draws on the experience gained and discusses the merits of the process.

Final Design / 1:200 & 1:100

The “wall” (*le mur*), one of architecture’s traditional (actual, conceptual, structural) building blocks, is the starting point for students’ concept formulations. Dividing space into opposites of exterior - interior, public - private, open - enclosed, the “wall” signifies the built form’s relation to its surroundings, defining and producing spatial conditions while at the same time being the interface between the user and the surroundings: both filter and boundary. Characterised by the principles *firmitas / venustas / utilitas*, walls not only reflect the structural, morphological or functional beliefs and capabilities of a society but also convey aspects of the dominant ideologies existent within it. *Le mur* (the wall), is viewed, in the context of the design studio, in isolation, as a scale-less element to be further defined (- designed) and re-interpreted through a reference to an idea, a vague theoretical concept that acts as a catalyst for the transformation of the wall into a complete and constructed architectural entity, one that still seeks to make reference to the vague and the theoretical, nonetheless through an actual fabricated construction.

The aim of the studio is to offer students a complete experience of architectural design, from concept to realization, focusing on the documentation, critique and re-thinking of the evolution of the idea into its built form. The studio seeks to engage students in bibliographic and field research and allow the knowledge gained from the theoretical discourse to be fed into the architectural design process and ultimately allow the latter to culminate into the constructed object. It goes without saying that this process is not linear but rather takes the form of iterative cycles between the three phases. Furthermore, the course aims to capitalise on the possibilities for collective thinking, engaging students in the critique, comparative appraisal, valuation and evaluation of their own and their peer’s projects and ultimately in the selection of concepts that progress to fabrication, allowing students to take ownership of their ideas.

In attaining the aforementioned goals, the annual course is structured in two – autumn and spring – semesters. During the first semester, students are asked to work in groups of two to four persons. Each team of students is then asked to propose for a theoretical concept, a vague idea lying outside the boundaries of the architectural discipline, to be researched. As mentioned previously, the theoretical concept acts as the catalyst for the transformation of the scale-less element of the wall; the outcomes of the theoretical research are required to set specifications for the design of each team’s wall, allowing concept formulation. The remainder of the first semester allows

time for the gradual transformation of concepts into preliminary-design proposals and then into general final designs of walls that still make reference to the original idea that generated them. The students' collective decision on three projects that will be further elaborated on during the second semester completes the first part of the course.

During the spring semester, students are reorganised in three large groups, each of them assigned one of the projects selected at the end of the autumn semester. Each team has to progress the work of the smaller teams, producing a detailed final design – including detailed working drawings and budget estimation. Moreover, teams have to select for a site for the construction of their wall which in cases entails a re-design of the wall for it to fit into a real location. The end-product of this process is the actual construction of the walls – the workforce comprising of the students themselves. However, the course does not end with the construction but asks the students to re-organise into their smaller working groups (of the first semester) in order for them to re-visit their original proposals and comment on them based on the experience gained in the second semester.

Throughout the progression of the course, students are allowed use of any means available to them for designing and testing their designs – drawings, physical or computer models, simulation software, etc. However, in order to facilitate a structured exchange of information between themselves and the tutors, their research and designs are reduced to two-dimensional images in order for them to be communicated through a BlogSpot; the virtual, scale-less, space of the World Wide Web is the vehicle utilized for exchanging ideas, information, concepts, and designs both inside and outside the studio, extending the “real”, “actual” educational space offered at the school's facilities. This medium allows students to actively make written comments on their peer's ideas and design proposals, actively engaging them in critique while at the same time constructing a journal of the evolution of each proposal – a diary of the course^{8,9,10}.

Details / 1:50 to 1:1

The actual building of one to three walls, among the design concepts proposed, and selected by the students themselves is the mandatory end-product of the annual studio. Taking place towards the end of the second semester, the construction of the walls reveals the inefficiencies that many times remain dormant in the concept formulation – design phases, which are commonly – in the context of architectural education – mistaken for the end-product of architecture, when, in actual terms they merely consist a conventional temporary phase of the whole process leading to the actual build. Moreover, the requirement for the construction of the walls entails the re-organisation of students from small into large groups that comprise the workforce for the final hands-on experience, allowing them a complete appreciation of their own designs – from the standpoint of the contractor / manufacturer. The two *wall* concept designs constructed during the academic year 2011-12 are presented in the following sub-sections.

Transform Wall

The concept of *transformability* is a recurrent theme in the context of the studio. Perceiving walls as rigid boundaries, students often propose the notion of transformability as a catalyst for re-interpreting the *wall*.

During the previous academic year (2011-12), transformability was researched through a modular construction that comprises of cubes interlinked via hinges, at any case allowing the rotation of each cubic module around an axis that is formed between two attached edges. A restriction in the types of relative movement between modules imposed during design experimentations focused students on exploring the full potential of a single type of joint (pivot) in achieving transformability (Fig. 1,2). The constructed *Transform wall* ultimately takes the form of a public piece of furniture that can accommodate various formal alternatives; in its deployed state it allows seating and interaction while when contracted it resembles a wall that allows a single opening.



Fig. 1
The constructed Transform wall.



Fig. 2
The deployed Transform wall.

De/-collage wall

The processes of collage and de-collages, consisted the point of departure for design experimentations in the creation of the *De/-collage wall*. The commonplace practice of gluing advertising posters on any available surface – a process that ultimately has the cumulative effect of various layers of paper glued onto each other and onto the wall – is utilized through the *De/-collage wall* as the raw material for the formation of instant public collage / de-collages works of art. The constructed wall (Fig. 3,4), suspended between two pillars that mark the edge of a public footpath, comprises of a grid of sliding parts within a rigid boundary; a two-dimensional jigsaw puzzle. Having two sides, the *De/-collage wall* allows the gluing of posters on one of its sides (the one facing the footpath), which for this reason remains flat, while the other side is marked with colour patterns and protrusions in order to invite users to play with the parts of the jigsaw puzzle, thereby tearing the posters glued on the other side of the wall – thus creating an involuntary de-collages – an instant form of public art.



Fig. 3
The constructed De/-collage wall (posters).



Fig. 4
The constructed De/-collage wall (puzzle).

Publication / report

The course was firstly conceived as a response to the changes that occur in the context of architectural education in Greece. First of all, the term *design studio* seems to be changing as the ratio of teachers to students is radically reduced. The participation of the whole class in the discussion of each project appeared as the only option for allowing a smooth operation on an everyday basis. The implementation of the collective intelligence of the group is proposed as an answer to the lack of teachers and the blog as a tool that served the need for sharing, involvement and cooperation. On the other hand, there are other types of changes that also occur in the education of young architects; digital technologies seem to be radically transforming our relation to architecture. Far from taking a stance in a technophile-technophobe dispute, the course is designed in a way that students can get in touch with tools and practices that combine digital and analogue technologies in a way that seems natural, as architects have always done with tools of different orders. Students are asked to utilise the absolute abstraction of a conceptual reference as a starting point and progressively move on to preliminary design, to general final design, to detailed final design and to the construction of a limited number of projects. From the scale-less reality of the concept-reference they reach the materialization of their project in a specific surrounding with specific providers, contractors and local authorities. The slim tolerances that digital tools and file to fabrication practices would expect, are questioned and renegotiated due to the low-tech construction possibilities offered. On the other hand, digital tools are used to control and check the function of their projects and lack of experience is often counterbalanced by thorough and double checking. Students find the realization of their projects extremely revealing and they are asked to re-evaluate their proposals after the materialization in order to shape and keep track of their changed perception.

Architectural education can only belong to the society that offers it; therefore it can only combine digital and analogue practices and, what is most important, the dissimilar perceptions and assessments that each one brings about. What the authors find most important is that young architects remain free to select and fuse their tools and

furthermore that a solid education is used not for reassurance and certainty but to instigate questioning and doubt.

Notes

- 1 Mantzou, Polyxeni and Bitsikas, Xenofon, "Proyectar en la era del código digital", *Actas Congreso Internacional EGAXII*, Madrid, 2008, pp. 489-494.
- 2 Moore, Charles and Allen, Gerald. [1976] 1978. *Dimensiones de la arquitectura, Espacio, forma y escala*. Gustavo Gili, Barcelona.
- 3 Terzidis, Kostas. 2006. *Algorithmic Architecture*. Elsevier, Oxford.
- 4 Focillon, Henri. [1943] 1983. *La vida de las formas y elogio de la mano*. Xarait, Madrid.
- 5 Allen, Stan. 1998. Terminal Velocities: The Computer in the Design Studio. Beckmann, John (ed.). *The Virtual Dimension*, Princeton Architectural Press, NY.
- 6 Bermudez, Julio and Klinger, Kevin. 2003. *Digital Technology and Architecture*. ACADIA Whitepaper, NAAB.
- 7 Rajchman, John, *Constructions*, MIT Press, 1999.
- 8 McLuhan, Marshall. [1962] 1993. *La galaxia Gutenberg*. Círculo de Lectores, Barcelona.
- 9 <http://lemurestdur.blogspot.gr/>
- 10 <http://lemurestdur11-12.blogspot.gr/>
- 11 <http://wallab.blogspot.gr/>

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**Research based Teaching
as a Model for Developing
Complex pre-cast
Concrete Structures**

Introduction

In schools of architecture there is an increasing focus on involving students in research. One reason is the possibility of saving resources when students contribute to research findings, as opposed to making arbitrary projects, the findings of which are discarded by the end of the semester. More importantly, involving students in research as collaborators, not helpers, creates a strong incitement with the individual student for learning and reflection within complex and highly specialised areas of architectural investigation. From the perspective of the researcher, working with students infuses the research with resources and ideas otherwise out of reach within the research framework.

This paper presents a case study 'ReVault', set forth as research based teaching. Based on a theoretical framework, didactic consideration, previous research, and earlier workshops that inspired the setup, the aim of the workshop was to work with students in developing a novel concrete construction technique. This led to the realisation of an amorphous concrete grid shell (Fig. 1), as well as the proposal of three didactic tools relevant to this mode of teaching.



Fig. 1

The research pavilion 'ReVault' - a result of a research-based teaching setup at the Aarhus School of Architecture in 2011.

Background

Theoretical background

The theory of *Tectonics* is used as a conceptual apparatus to qualify decisions in developing the casting method. Tectonics can be described as the relation between material, technique, and form (Fig. 2 left) [Christiansen 2004]. This definition is derived from the German architect and theorist Gottfried Semper, who describes tectonics as the description of a unity between idea, action, and construction [Semper 1851]. Or, generally speaking, the unification of means and end [Frampton 1995].

In order to effectively investigate geometry and techniques related to concrete casting, the MTF-model has been developed to include construction and the mould,

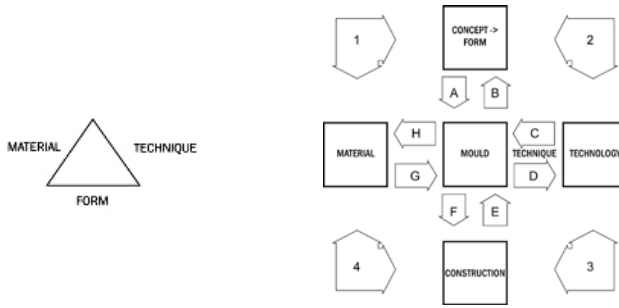


Fig. 2

Left: Tectonics defined as the evaluation of relationships between material, technique, and form. Right: A proposed relational model that places the mould in the centre of a realisation process addressing complex shaped constructions.

in a *relations model* (Fig. 2 right). The mould has the central position in the model, because it directly generates form. (Pedersen 2011)

Previous concrete workshops

The workshop setup builds on a student driven research-workshop format developed by Architect Professor Karl Christiansen and Architect, Lecturer Anders Gammelgaard, who conducted two workshops, testing aspects of their research into concrete casting in hotwire-cut polystyrene molds. In these workshops, one in Rome in 2004 (Fig. 3) and one in Berlin in 2005 (Fig. 4), students worked on exploring the potentials for creating two typologies, the column, and a column-beam assembly, respectively.



Fig. 3

Workshop result, La Sapienza, Rome.



Fig. 4

Workshop result, Berlin.

Background - Research

The research here presented acted as input for a masters studio where the research-based teaching environment, and specific concrete development, described in detail in this paper, took place.

This research is an investigation into new ways of casting unique concrete elements, in which there is a close connection between the material, the technology, and the form of the concrete element. The project addresses two problems in the current production of concrete elements:

- The lack of connection between the intention of creating variation in our build environment, and the current ways of shaping concrete elements.
- The environmental challenges, which primarily call for a reduction in waste products generated in the production of concrete elements.

The hypothesis is that these problems can be addressed by taking a starting point in the term tectonics and the modern technological situation, new industrialised methods of producing individualized concrete panels, can be developed. Methods which are capable of competing with a traditional production of standardised elements, and at the same time have an inherent, added architectural value, and a better environmental profile.

This hypothesis was presented to the students, and served as a framework for the study brief and assessments. The study brief presented the students with the following question:

How can modern technology unfold the formal potentials of concrete, creating concrete with a high architectural value while maintaining a production line that is environmentally sustainable?

A series of theoretical and material investigations were conducted prior to initiating the studio in order to generate a foundation for the studio to build on.

Background - Teaching

The teaching setup in which the research was utilised focused around a specific methodological approach. Central to this was a responsive design process shifting between design techniques with potential digitalization, material qualities and digitally based fabrication. This approach framed the work and challenged the collective as well as the individual process and project development in uncovering potentials for a tectonic approach to architecture.

This architectural analysis considered parametric terms and the script language, in order to deal with the complexity of adaptability in architecture. In other words, the aim of the teaching was to make students consider how digital technology can resist becoming an objective in its own right but rather a means for supporting the human being as the objective of architectural creation.

The semester assignment and individual project development were based on 3 elements:

- The tectonic approach, focusing on the Material – technique – form relation. (As described in section 2.1)
- The workshop, investigating a responsive design process, also referred to as a digital tectonic approach.
- Site & Program narrative story - Uncovering the existing conditions and fantasizing of future potentials.

This paper focuses on the two first focal points.

Material background

As a material basis on which to build the research-based teaching setup, a novel casting method was developed.

To ensure the feasibility for full-scale production before using the technique as a basis for research-based teaching, the casting method was conceived and developed by the author in a sculpture entitled 'Hello World' (Fig. 5).

Since the moulds would all be unique, and therefore not reusable, a materially efficient and low or zero-waste production method was desired. This was achieved by the use of PETG plastic, which is part of the PET plastic family. It is easily recycled, by melting, at 260 °C, evaporating only CO₂ and water, and its molecular structure allows for infinite use and re-use without degradation if it is kept in a closed recycling process. In terms of the design theory Cradle to Cradle, the PETG is used as *Technical Nutrient*, in a zero-waste production [McDonough and Braungart, 2002]. Importantly it does this while adhering to the basic requirements of being an appropriate mould material that is easy to laser cut and easy to fold. The plastic sheet comes covered with a thin protective film, used to protect the material against scratches during transport. This film was left on during casting and then removed to leave a clean sheet ready for recycling.

When exposed to fluid concrete material, 1 mm PETG sheets have a high degree of deformation. It was practical to perform stress and deformation simulations as part of the development of components, in order to check that the PETG could withstand the weight and hydrostatic pressure from liquid concrete (Fig. 6) [Pedersen 2011].



Fig. 5

Material research background: A series of parametrically defined, reinforced concrete beams and columns, cast in PETG plastic.

Didactic background

In order to point towards possible ways of merging research through design in with research-based teaching on a masters level, it is relevant to present some basic consideration regarding theory of learning. This is particularly important to prevent what is referred to as misalignment [Keiding et.al 2007] – a situation where a discrepancy occur – often inadvertently- between the presented learning goals and the actual learning. In this case a misalignment may arise between the narrow focus of research as opposed to an architecture study programme that is required to provide a much broader perspective on architecture. (Studieordning for kandidatuddannelsen på Arkitektskolen Aarhus, 2012)

The learning theory *constructivism* offers a view of the individual as a constantly active part in the generation of knowledge, as opposed to an active recipient of instructions. As such, learning is formed by the individual and individual's capabilities to build up knowledge, not a direct translation of knowledge from teacher to individual. (Dewey, 1938)

It follows that the teacher must acknowledge that the student is a participant in forming realisations about architecture.

This is in contrast to the tightly controlled workshop, where the workshop leader / researcher has a clear idea about what the output of the workshop should be. This approach draws on behaviouristic learning theory, in which the master dictate solutions, which the students acquire by means of copying the master.

When the teaching is taking place on a masters level, a challenge occurs, because the level of specialisation is high, while the area of investigation is complex and abstract, requiring a great deal of self study and reflection from the students.

The studio setup described in the following is an attempt to achieve both a high degree of specialisation, while insisting on students taking initiatives to take decisive steps, something that is essential in a workshop with a high level of complexity.

Case: The workshop

A case study was built on the background research and didactic consideration, and was carried out as a focused investigation, where students and researchers collaboratively developed and realised an amorphous, catenary grid-shell.

Specifically, the workshop investigated the application of small-scale components with triangulated surfaces and a small casting height, in order to eliminate deformations due to the hydrostatic pressure of concrete. The case study was carried out at Aarhus School of Architecture in the fall of 2011 (Fig. 7). Over the course of three weeks the authors, with the aid of Civil Engineers Jacob Christensen, and Ronni Madsen and 12 Master of Architecture students, designed and built a 16 square metre by 2 metre tall pavilion consisting of 110 discrete concrete elements, cast in PETG (Fig. 6).

Division of responsibility

To allow students to conduct focused investigations and development, The students were organised in four groups:

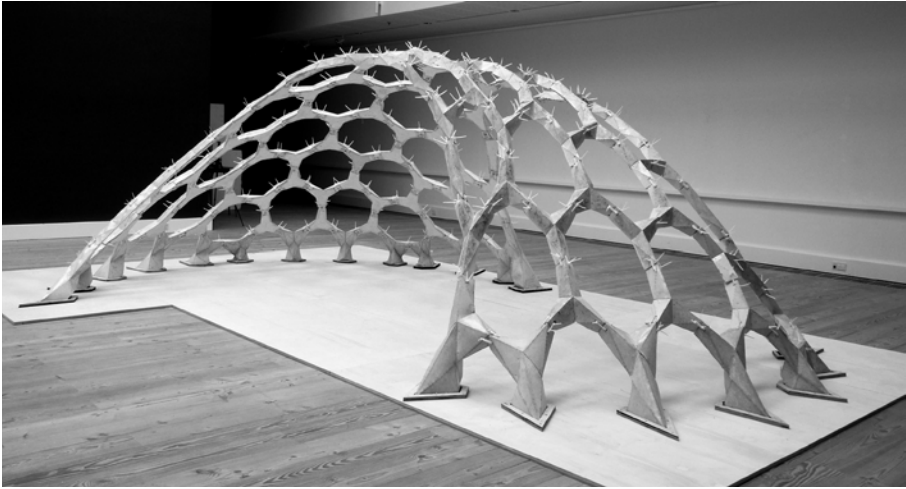


Fig. 6

The ReVault case study: A concrete grid shell pavilion made up of 110 discrete.

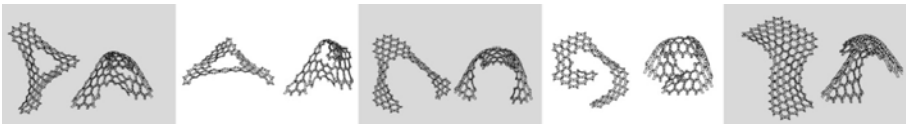


Fig. 7

Investigation of different geometries by the overall geometry group.

- Overall geometry / form finding
- Component design
- Falsework
- Connections

Overall geometry / form finding

The overall geometry group used a method for form finding using dynamic relaxation of a network of flat curves. This created a three-dimensional wireframe mesh, from which the task was to generate volumetric concrete components (Figure 7). This meant that the group had to work closely with the component design group, as well as with engineers, who conducted Finite Element analysis to calculate the shear forces and bending moments in the joints.

Component design

The molds had to be manufactured from 900 x 1600 millimetre sheets of PETG. The component design group determined the size and shape of the individual components, so they were able to meet the pavilion shape suggested by the overall geometry group, while respecting material and production restraints (Fig. 8).

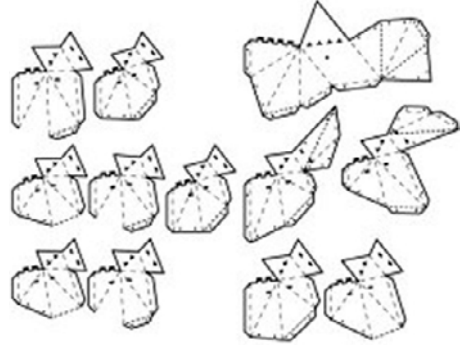
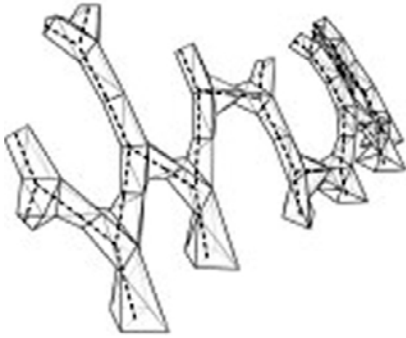


Fig. 8

Right: the final component design.

Left: The component design group learned a scripting language to parametrically generate templates for lasercutting.

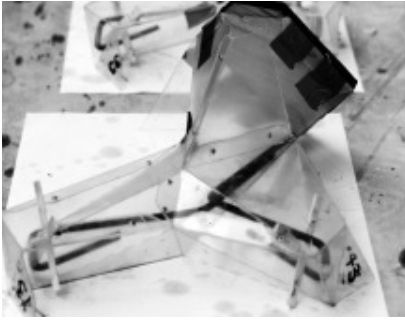


Fig. 9

The mold for one of the base components.



Fig. 10

The structure being assembled against the parametrically generated falsework.



Fig. 11

The 'worst-case' prototype after structural failure.

One important development in this area was the triangulation of each component arm, which added stiffness to the mold while allowing the component to meet the many different angles that occur when an amorphous overall form is panelised. Development also addressed the need to stay within tolerances. The PETG moulds were fixed to a blueprint, generated from the digital model, which enabled positioning of the ends of the three component arms with a tolerance of less than one millimetre. Flaps added to the ends dictated the angle of the component arms (Fig. 9).

Falsework

A prototype test (Fig. 11) disclosed that precise falsework would be important to position the components correctly in the compressive arc. This led to the task of designing and drawing a viable, parametrically defined falsework, generated directly from the spatial components model using *Grasshopper*, a generative modelling plugin for *Rhinoceros*. Fabrication was done by means of laser cutting recyclable cardboard (Fig. 10) [Pigram et al. 2012].

Connections

Principally there would be no shear forces in the joints, the structure being in pure compression. To test this, a worst-case prototype, with no connections, was constructed. Also, Finite Elements analysis was used to calculate the shear forces in the joints. Failure of the prototype and the appearance of shear forces in the FE analysis provided the students with evidence that a connection pulling elements together would be important.

Shear happened due to the large passage openings in the mesh, and due to lack of precision, both in the production of the components, and in the process of assembling the structure. The development of several connection details began, and resulted in the implementation of zip-tie connections.

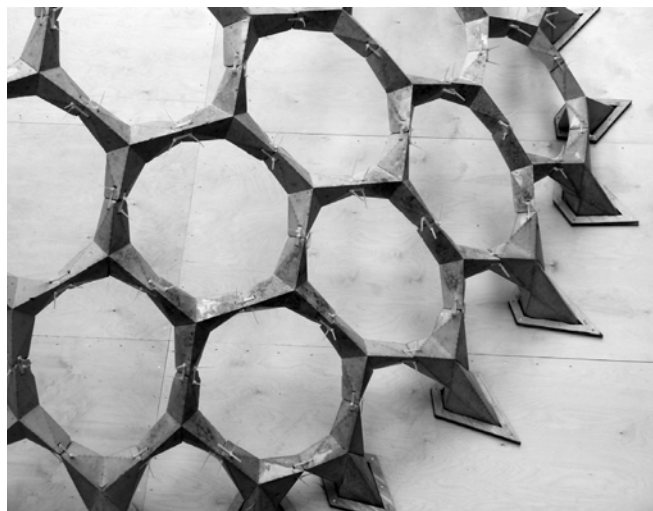


Fig. 12
Component connections.

Impact on Teaching

The semester projects that followed the ReVault workshop were qualified by both the method and the findings, regarding material observations as well as parametric and algorithmic workflows. As an example, one student developed a fabric casting system using gravity simulation software to generate templates for casting concrete in catenary arches using fabric molds (figure 13).



Fig. 13
Concrete casting by master student Jon Andersen.

Findings

Didactic tools on a general level

On the basis of the case study three didactic tools have been identified. They serve to qualify both teaching and research output, when the mode of inquiry is research by design, involving students. In other words, they are proposed as tools that may help bridge the gap between research and teaching, between the specific problem and the generalist nature of studying architecture.

- Knowledge generation between researcher and student
- The advanced investigation as a booster
- Interdisciplinary collaboration

Tool #1: knowledge generation between researcher and student

Typically students produce a semester project, which is conducted as project work. This tool includes a widening of the term “project work” to include the research into this project work. This is done by including the workshops into the curriculum, and most importantly, by creating an environment where the goals for the studio and research are achieved *with* the students, as opposed to being an assignment posed by the teacher / researcher for the students to carry out. Importantly the establishment of a common ground also involved the alignment of a theoretical and methodological framework, in this case tectonics and research by design.

This happened by initiating the semester with the ReVault workshop, in which the students took responsibility for the different experiments needed to develop a complex case study. Importantly, the study should be one in which the teacher has an incentive to participate in, because of its relevance to his or her research. The relevance to students should be secured by inscribing the learning outcome in the study brief in such a way that the students can use the findings in the following semester project.

Tool #2: the advanced workshop as booster

This leads to the second tool, which is more of a strategy: To start with a narrow and framed exercise, that enable the students to produce an output with a very high quality, while introducing and encouraging a research-like approach to the following semester project. In other words, to raise the bar. The ReVault workshop serves as an example of this strategy. An important part of the strategy is to formulate an open problem for the remainder of the semester, allowing the students to demonstrate independence and to establish a learning environment in following a constructivist approach.

Tool #3: interdisciplinary collaboration

It is important to prevent the research from becoming too specific and peripheral to the students. Equally important is that the output from teaching has relevance to the researcher. This may be prevented by establishing a cross-disciplinary collaboration between multiple researchers, in which the researchers define a theme that has relevance to teaching as well as their respective fields of research. This broadens the field, increasing the relevance for students thus minimising the risk of mis-alignment. Also, it creates an opportunity for researchers to have their field of research meet another, which puts the research into perspective and open the possibility for findings that would not be otherwise possible. In the case described here, research into the tectonic potentials of concrete by the author, was infused with research into parametric and algorithmic design by Architect, Adjunct Niels Martin Larsen and Architect, Associate Professor Dave Pigram, which, along with the inclusion of Engineers, made the case study possible.

On a more specific level, didactic considerations involved a division of responsibility into smaller areas of investigation, allowing the students to conduct relevant experimentation while negotiating other areas of the research. Also, the presentation of the concept of tectonics, provided a means for discussion, evaluation, and qualifying of decisions.

Conclusion

A research based teaching setup is described, in which students and researchers work collaboratively on the same project, proved to have several advantages. The quality of learning outcome and research output was maintained by the establishment of a setup including researchers from multiple fields within material and computational research. This broadened the field, preventing a too specific learning environment. Utilisation and development of algorithmic, parametric and material techniques necessary to create a complex pre-cast concrete construction technique was possible only be-

cause students and researchers worked side-by-side. The workshop served as a booster for the following semester project, in which students utilised the workshop findings in their own projects.

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Purpose Driven Computational Design Teaching

**Embracing environment restrictions
in computational design**

Design elegance: goals and strategies

Manifesto

In mathematics, the proof of a theorem exhibits elegance if it is surprisingly simple yet effective and constructive; a computer program or algorithm is elegant if it uses a small amount of code to great effect.

Similarly, our goal is to produce elegant design.

The work of F. Otto and others at IL, was a fundamental and brilliant production of research around lightness in the urge of energy reduction context. They were emphasizing how form is related to forces and matter, and setting up lightness measures such as BIC¹. Very influenced by they work, we consider that manufacturing process shall be taken also into account, and the unit to legitimately integrate efficiency in any design should be ecological footprint.

Form is then driven by the balance of three fields: force, matter and process.

Forces are determined by the functions and expected uses and lifespan of the design. They are determining which behavior is the object intended to reproduce. Matter are the potentials and restrictions of the materials in use and their intrinsic properties potentials. Finally, processes are the dynamics and resources involved in the geometry emergence that affect deeply the final result both in form and efficiency. As in a morphogenetic process, form emerges form a symmetry breaking cascade: from very abstract to concrete, form upper top imposed environmental conditions, to a decision driven gradual concretization, an increasing combination of these three fields (Table 1).

Table 1
Fields and strategies.

Manifesto		
<p>Force</p> <ul style="list-style-type: none"> -Form follow forces -minimize stresses <p>surface:shells, lineal: branchings, hybrid: ribs</p>	<p>Matter</p> <ul style="list-style-type: none"> -Low ecological footprint -Reuse, Renewable, Recycle <p>Timber, Metals</p>	<p>Process</p> <ul style="list-style-type: none"> -Low energetical process -Based from standard products -Smart/minimal manipulation <p>Bending, folding, cutting, drilling, sewing, melting</p> <ul style="list-style-type: none"> -Handeable ---- -Low tech
<p>Force-Process</p> <ul style="list-style-type: none"> -Efficient form from simple process <p>Bending, Torsion, buckling, snap-buckling</p>	<p>Force-Matter</p> <ul style="list-style-type: none"> -Form follows performance/behaviour -Exploit intrinsecal material properties -Lightweight structures -High tensile strength, low bending stiffness materials <p>elastic composites</p>	<p>Matter-Process</p> <ul style="list-style-type: none"> -Minimize cut-off -Complex shape with lesser elements -Big shapes from small elements (handeable) -Fiber/crystal orientation use <p>scissor structures, expandables</p> <ul style="list-style-type: none"> ---- -Avoid additive/substructive
<p>Force-Matter-Process</p> <ul style="list-style-type: none"> -Efficient form through simple process involving material behaviour <p>Active-Bending, deployables, thermoforming</p>		

Designer has to be nifty enough to set these boundary conditions, to set up the topology, and leave the form acquire its metric.

Design evenly integrates forces, matter and processes in a holistic yet simple solution. Design is the equilibrium state of a system where several energies are acting, the least strain solution. Design process is the energy minimization problem description and further solving, then elegance may happen.

Restriction oriented teaching

After years of virtual economical growth, and fireworks architecture, computational design teaching often lack of purpose and architectural design teaching is then mistaken with a blind teaching of limitless tools. This context is leading to the proliferation of meaningless formal aberrations, under the self-legitimation by the means of novelty of the tool itself or the oddity of the form.

Nevertheless computational design tools enhance design and intuition, not making things more complicated, but rather complex when providing a better scientific and objective frame to design.

In this collapse-risk world, academia has the responsibility of seeding environmental concerns, and good practices. It's not about moral, it's about cooperation and common sense, it's about resources running out and design solving problems and not generating them.

The challenge but also the opportunity of computational tools is to bind real world physical constraints (in behavior, properties, processes) in the digital world. Then, design tools may be given as a complexity integrator.

Permeable

The fast growing development and knowledge sharing of computational tools, suggests reliability in the increasingly faster learning of new generations, thus the potential in the bidirectional instructing.

Collective learning happens inevitably in this enthusiastic frame of mixing students and teachers. Content, after research and experimentation is thus generated by both parts, and then is set highly accessible in the net to be muted and give birth to something better.

Nevertheless teachers are indeed responsible of the scientific design of the joint-venture research process of posing problems, collecting data, and elaborating conclusions.

Optimism

Optimistic vision of challenges are key to solve them. Teaching is encouraged to integrate fun as a value and driving force.

In one hand, failure is always an option, otherwise why even trying it? It's not the content but the process which matters, the "philosophy of doing" that prevails as Otl Aicher was pointing. In this direction, "disaster workshops", the casual curiosity driven

research, are fundamentally positive in design learning, leading to unpredictable results. In the other hand, fun has formats. Design, and precisely computational design, need specifically both amounts of fun and geekiness. Thus the induction of uninhibited scientific and technological frame into the course is highly profitable.

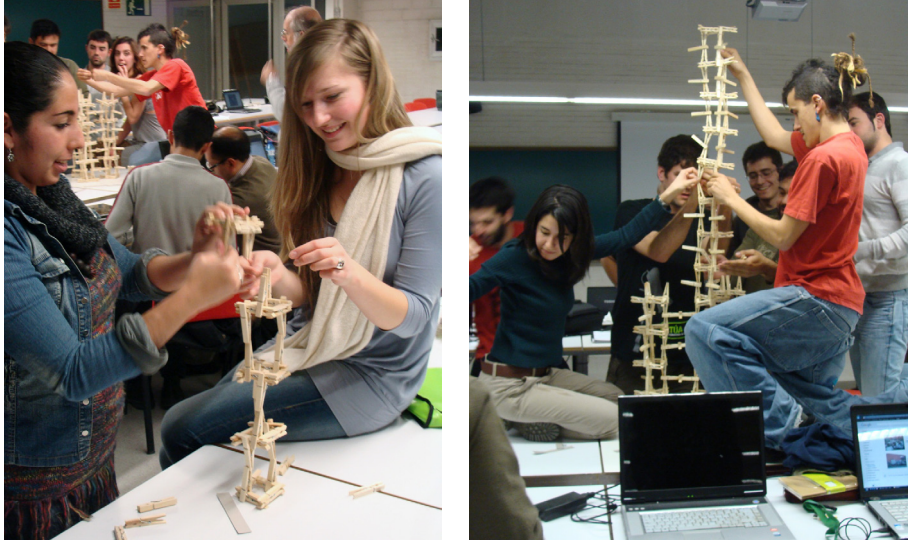


Fig. 1
Clothespin disaster workshop.



Fig. 2
The ultimate percience lecture.

Innovation Research Teaching

We promote a transversal relationship between academy, research and innovation, where academy plays a critical experimental ground to test concepts coming from research core, that will furthermore, derive in innovation products. Classroom sparking enthusiasm is a great opportunity to critically test concepts and goals. [normal]

Studiescases

AP12: Parametric Architecture course [06 Headings]

Dome Athletics (Fig. 3) is the collective result from Parametric Architecture course at ETSAV, where degree, master, PhD students participate. Groups have to build twice a shape: first as a laminar continuous surface, then as a discrete structural lattice. The shape received individually is a dome generated with an inversion form finding, thus a compression laminar shell. All domes are nevertheless different, and groups may find an adequate strategy.

Strict guides have to be followed. Material is given and students have to focus in their properties. Work is 1:1, thus experimentation is a fundamental part of the course to positively feedback digital abstract frame. Manufacturing is laser cutting, and assembling is strictly by geometry joinery, while mechanical help is not allowed. We encourage to minimize cut-off, and to simplify assembling, while ensuring global stiffness.

The risen knowledge is positively collective teaching: an aggregative repository of exchangeable procedures. Students and teachers generate collaboratively the class material, the unveiling typologies from the shared topology.

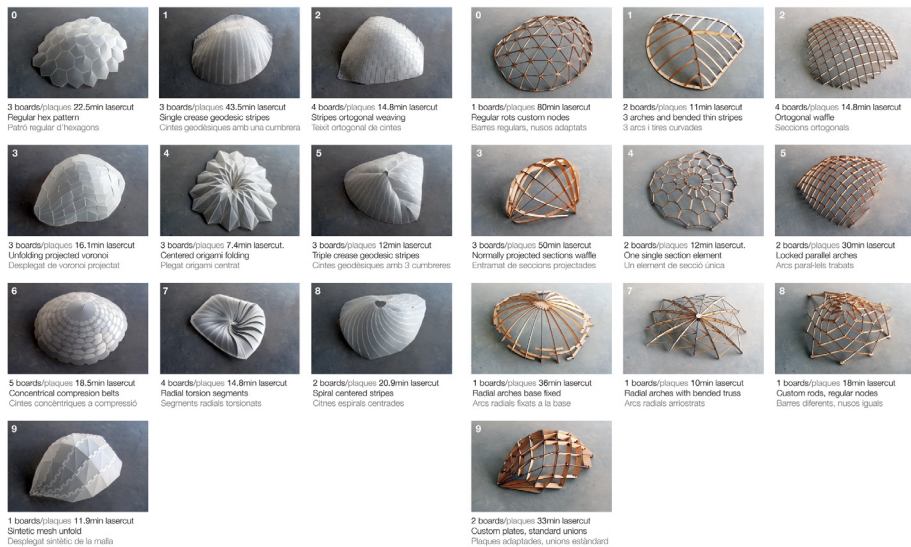


Fig. 3
Dome Athletics.

Jukbuin Pavillion

In the context of the EME3 architectural festival in June 2012 in Barcelona, the research group had the opportunity to build a self-standing structure. For this special circumstances (reduced budget and assembling time) an active-bending gridshell is chosen as design system.

Recent capacity of simulation techniques² and the revisions in active-bending structures³ have provided a brilliant production of novel lightweight timber structures⁴. Nevertheless, some of these structures sharing the advantages of self-forming curved elements from straight and planar elements, seem to lose the efficiency of historical and vernacular active-bending structures, provoking material waste and demand in high technological resources and energy.

In the current challenges of energy depletion world, building solutions are called to be more efficient and requiring less resources. In this lightweight race, the potential of active-bending structures and the seduction of the slenderness and rigidity of weaving techniques, triggers the exploration of traditional basketry.

In historical structures where bending is used as a self forming process (as in wickerwork), reveal first, the empirical, behavior based approach, intuitively used historically (form out of material organization system elasticity), opposed to the analytical, geometry based approach, used by engineers to build effectively (form is predefined: active-bending is used as an economic manufacturing technique) and the geometry-behavior based approach (a more recent combination of both strategies).

The research proposes a combined strategy of building a lightweight gridshell with a low-tech fabrication process based in vernacular weaving techniques and using strictly industrialized boards. The goal is to minimize energy and material waste, in the manufacturing process of an efficient structure while simplifying assembling process.



Fig. 4
Jukbuin Pavillion.

The ultimate goal is the universalization (simple, affordable) of lightweight structures through active-bending strategies. For this challenge the complex geometrical problems are solved modeling pseudo-physical materials properties: in this behavior approach, an elastic fabric is simulated to produce the erected final shape⁵.

For the festival context, the elastic gridshell proved its advantages of self-erecting while standardizing elements reduced project cost and made assembling very easy, fast, and specially feasible with non specialist builders. A crew of students helped to weave and erect this uniform and non-hierarchical fabric assimilating the building technique to the bottom up organization system: assembling small elements for a collective fabric. Characteristics: 15 UPM Wisa Birch standard boards sawn into 5 cm battens: 280 repeated pieces and 30 different pieces (257 Kg and 93 m² covered (2.8 Kg/m²). No screws, no waste. 1 day erecting. Budget: 1500€

FTH Featuring the Hits

The research group behind teaching is committed to the cultural integration of science discoveries and new technologies. FTH Featuring the Hits is a series of open events to share cool things and learn new ones. Smart people sharing nifty things done with computers (or not). By this series of shifts in regular courses, students get another approach of the uses of computation as a cultural fact, and open indeed their will in parallel fields, leading lately to a more rich design environment.

Conclusions

The paradigm shift that computation has brought into our society has been often misused by design fields. The increase of drawing capacity was not bonded with an increase in efficiency.

Nevertheless, *design is not about standing the drawn, but drawing the standing*. Computational tools shall not lead to building extravaganza, but instead enhance elegant solutions. We envision the elegance as the energetic minimum of several concrete actors involved. As designer Otl Aicher downplays the role of pure reason and critical rationalism of modernity as a result of the predominance of a mere abstract thinking, we endorse the “philosophy of doing”, and the reivindication of the analog and concrete above the digital and abstract. We claim high tech design, and low tech fabrication.

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- Persons: Daniel Piker for the advices and the software Kangaroo, Andrés Flajszer for the credited photos and warm support.

Notes

- 1 Otto, F. et al, *IL 22 Form Force Mass*, IL 22. Institut für Leichtbau Entwerfen und Konstruieren, Stuttgart, 1988
- 2 J. Lienhard, S. Schleicher, J. Knippers: Bending-active Structures – Research Pavilion ICD/ITKE, in Nethercot, D.; Pellegrino, S. et al. (eds) *Proceedings of the International Symposium of the IABSE-IASS Symposium*, London, UK
- 3 J. Lienhard, H. Alpermann, C. Gengnagel, J. Knippers: Active Bending, a Review on structures where bending is used as a self formation process. *Proceedings of the International IASS Symposium*, Seoul, Korea
- 4 Lafuente E, C. Gengnagel, S. Sechelmann, T. Rörig: On the Materiality and Structural Behavior of highly-elastic Gridshell Structures, Computational Design Modeling: *Proceedings of the Design Modeling Symposium* Berlin 2011, Springer; 2012 edition
- 5 D. Piker: *Pseudo-Physical Materials*. <http://spacesymmetrystructure.wordpress.com/2011/05/18/pseudo-physical-materials/>

**Designing, Fabricating
and Teaching
the Seamless
and the Scaleless**

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**Computational Experimentation
and Design Research:
Two Case Studies
in Architectural Education**

Introduction

Architectural design unfolds through continuous representations, as an interplay between abstract drawings and aesthetic choices. Representation techniques are never neutral; architecture's abstract means of imagining and realizing form leave their traces on the work.¹ The "physical" properties of the production means - including the digital ones - interfere with the design process, specifically in the ways content is manipulated. In particular, the digital working platform presents a set of special attributes being different from those of the analogue one. The designer moves from total to detail, also from abstract to specific and back again, potentially inverting traditional design hierarchies. Additionally, design conventions primarily referring to scale, or the clear separation of the production phases are directed by the experience of working with the analogue tools, rather than by the computer's logic. Moreover, the use of computation for design purposes often invokes an "abuse" of the digital environment's features, constantly demanding for an updating of hardware and software; in turn, computation may not only be viewed as an aid to the analogue practices, but more importantly as a medium being formative of creative thinking. Computation's generative aspect of design has caused a radical shift in the methods of representation about architecture, one that has further been recorded in the project's actual form.

Following the above view, this paper presents the organizing structure and the findings of *AB-Use* workshop and *Code Species* advanced semester studio, both held at School of Architecture, University of Patras, in 2012.² The objective of the two courses was to explore the possibilities opened up by the incorporation of computation, especially of scripting in architectural design. The two courses used the scripting platform of MEL (Maya Embedded Language), being integrated in Autodesk Maya design software. Key concepts and techniques of parametric design were developed, as these were also compared to more conventional ones of digital representation. The theoretical basis of the courses was enriched by the produced material and by related courses taught in other schools. Among the findings is the observation that architectural education has already embraced the digital medium in the form of a multifaceted challenge, mainly in studio research. Because of the overall appeal of the new techniques, also of the sometimes intense criticism that computation has received upon its entering in the architectural studio, it is beneficial to evaluate the main idea underlying the two courses along with the produced results. The related experiments acknowledge the wide spectrum of approaches taking place somewhere in the borders of architectural education, also in relation to other disciplines; meanwhile it has become imperative to construct a common ground being supportive of the different views that have risen, especially in conjunction with the core theory of architecture. In respect, the presented work may be an addition to the ongoing discourse, further identifying this new field.

Two case studies: *AB-Use* and *Code Species*

AB-Use workshop

As a starting point of *AB-Use* workshop (Fig. 1), programming was introduced by techniques applied in digital art. Computation offers more than the automatization

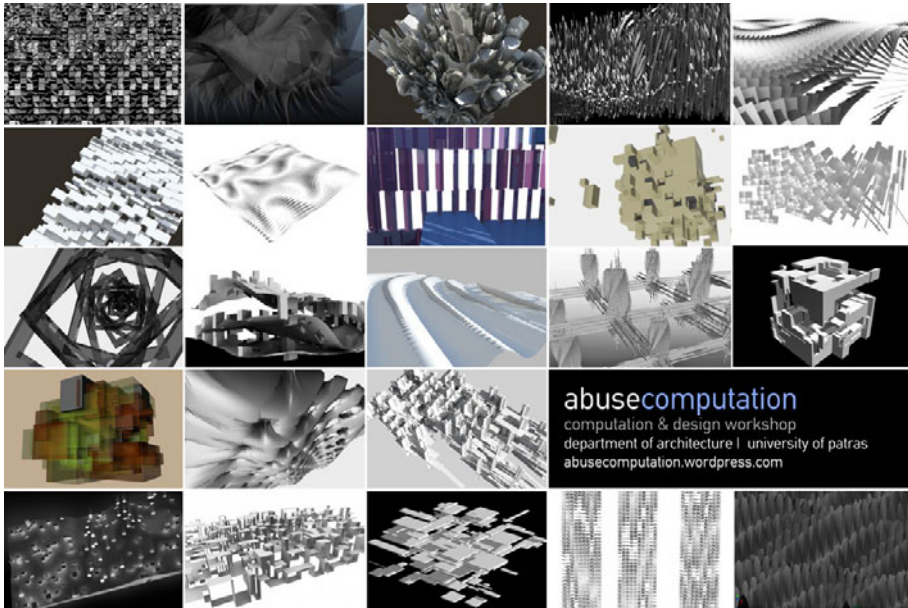


Fig. 1
 AB-Use workshop, selection of works.

of known procedures. It widens the spectrum of the available methods and systems having experimental character, also offering new research patterns. Factually, it is acceptable that the digital working environment, apart from facilitating design actions, it shows new possibilities causing selectively the disengagement from preconceived forms, geometries and aesthetic rules. This shift happens along with a quest for new morphologies, also having to do with a set of advancements regarding the production process, such as the simulation of dynamic relationships among the parameters of design, the systematic exploitation of structural diagrams, the understanding of qualitative and quantitative variables as active agents and the utilization of the timeline, also of animation and deformation techniques. Evolution has happened along with an increasing interest in scripting and the dynamic function of code. A script addresses the elements of design, their characteristics and overall behavior and the parameters influencing the relationships among them. With the use of MEL programming language combined with the layout of Maya, it was possible to constantly test a script through the evaluation of its results presented on the screen, also to develop compound design methods, including applications of code together with manually-driven processes. Moreover, the parametric methods were often compared with more conventional ones of computer design usage. The workshop was gradually progressing, and so adding up to the level of familiarity with programming accomplished in each session, also in relation to the desired results. It consisted of a general approach of the digital code, then some geometric applications in the digital space and finally a set of manipulation techniques about surfaces and their components. The sessions are as below:

1st session: (MEL Scripting Basics). The students are introduced to characteristics being common to most computer languages. These include the definition of variables (declare / assign variables), the different types of variables (string, int, float), lists and aggregations of objects (array, matrix), parametric commands, structuring of commands with composition of words and parameters (concatenation), the formation of conditions (if), the syntax of conditional repetition (for & while loops) and finally the use of the output panel (print). The objective is to acquaint the students with the structural logic and the fundamentals of scripting, which will be used later on in geometric applications in two and three dimensions.

2nd session: Geometry basics. First contact with polygonal geometry is made with the creation of simple shapes with scripting, gradually evolving to more complex ones (Fig. 2). The unit includes the development of polygonal surfaces (polyPlane) and three-dimensional shapes (polyCube, polySphere, polyCylinder), the assignment of random values for the control of the properties of geometric shapes in relation to size and position and the manipulation of the geometric components (Vertex, Edge, Face). The goal is to visually express methods of repetition and flow set by the script. By changing the parameters of size, number of repetitions and conditions, a variety of outcomes occurs.

3rd session: Object arrays, clouds. Grid systems in two and three dimensions are produced, following controlled and randomized transpositions, also change of scale and size. From these processes, it is possible to create a set of emergent densities, loss of control such as noise, deterioration and irregularity (Fig. 3). The present session makes use of methods of repetition (for-loops) for the creation of swarms of objects having varying qualities. The goal is to use variation in response to predefined objectives, also by experimenting with change of parametric values within specified range.

4th session: Scripted boolean operations. Boolean operations such as Union, Difference and Intersection are applied repetitively as parametric commands of algorithmic code (Fig. 4), then they are related with the basic properties of geometric shapes presented in the 2nd session (geometry basics). From such a collaboration, a variety of space arrangements emerges having very different formal characteristics. Then, boolean operations are put to function together with applications of the 3rd session (object arrays, clouds) for the creation of compound solids deriving from swarms of objects. With this process it is possible to study comparatively the spatial properties related to semantic dipoles such as void / mass, rhythm / interruption, interior / exterior, soft / intense, analogy / arbitrariness, as these may be controlled numerically by the script.

5th session: Introduction to gradual differentiation. This session focuses on mathematical operations related to progression and common trigonometry functions combined with Move, Rotation and Scale commands, applied on basic geometric data (Fig. 5). The notions of continuity and gradual differentiation are related to polygonal geometry set to polygonal arrays and surface components. With these operations, a variety of surface qualities may be defined, such as density, thickness and size of component parts, by changing their properties in relation to position. The combination of continuity and differentiation reflects contemporary research on the creative use of para-

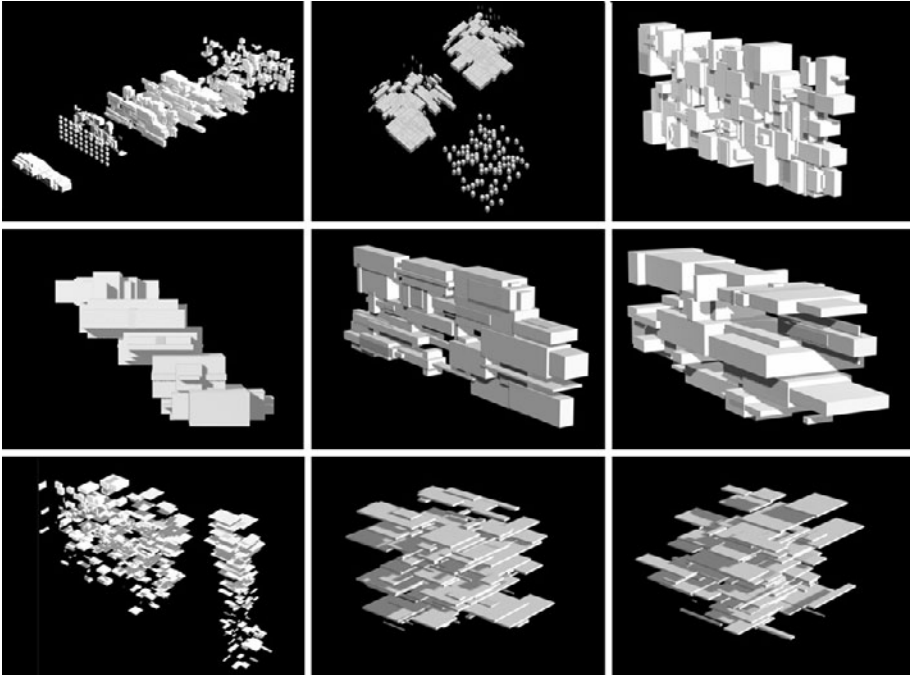


Fig. 2
 AB-Use, 2nd session. Geometry basics.

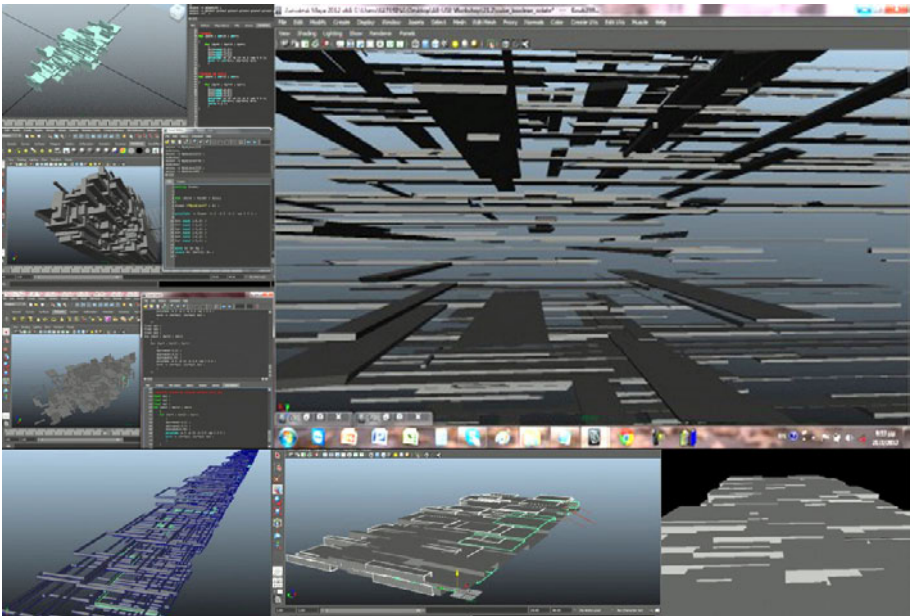


Fig. 3
 AB-Use, 3rd session. Object arrays, clouds.

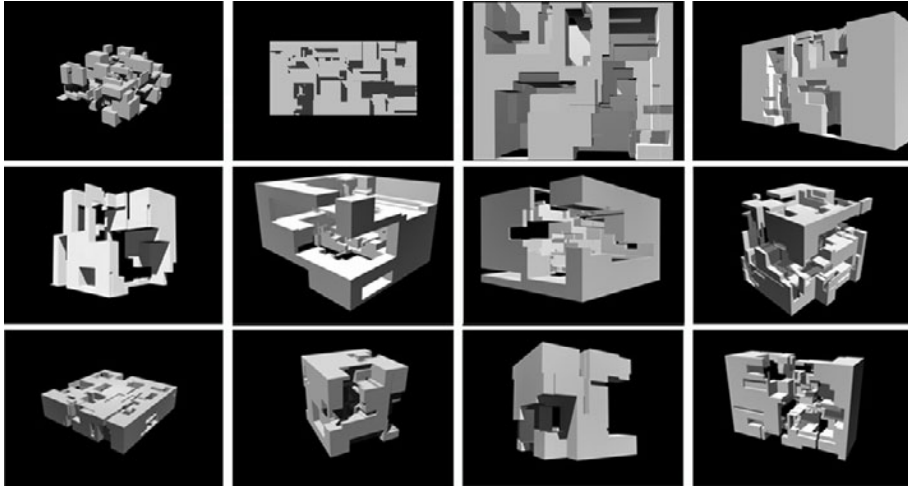


Fig. 4
 AB-Use, 4th session. Scripted boolean operations.

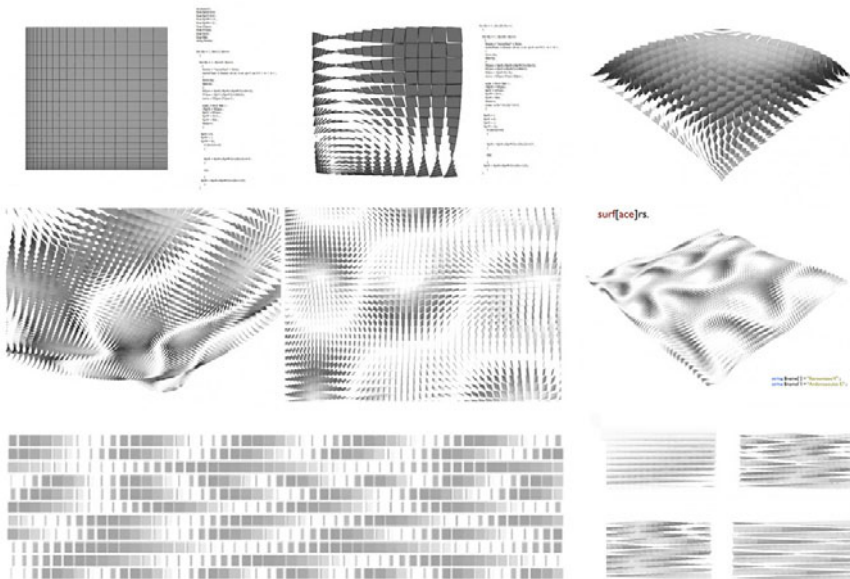


Fig. 5
 AB-Use, 5th session. Gradual differentiation.

metric operations for the definition of new vocabularies about structures, typologies and archetypes and their understanding as dynamic, rather - than static - organizing schemas.

6th session: *Emergent surfaces*. This session introduces script-based Extrude and Loft operations applied on curves for the creation of surfaces (Fig. 6). The goal is to gradu-

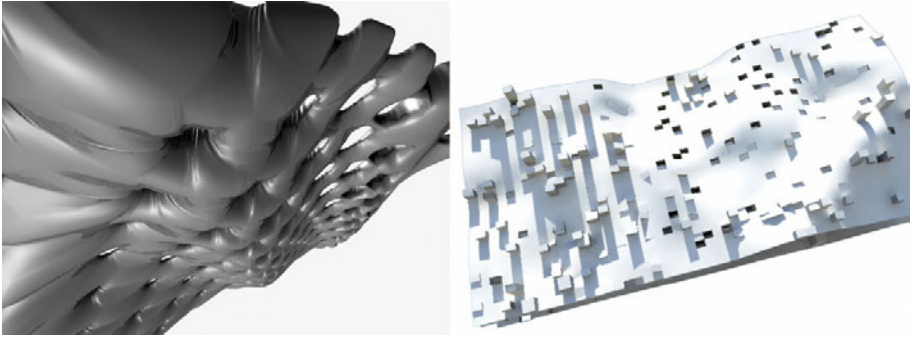
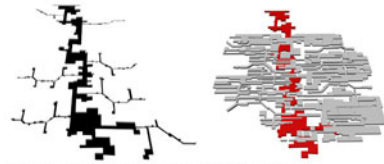
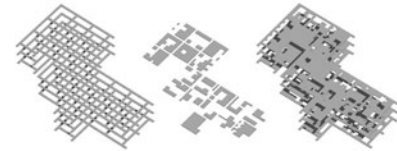


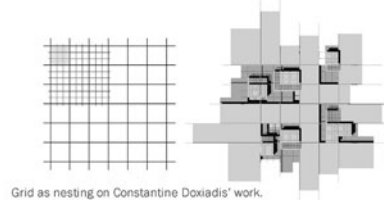
Fig. 6
 AB-Use, 6th session. Emergent surfaces.



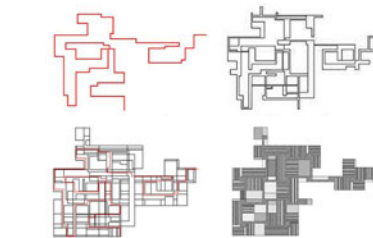
Stem. Candylis-Josio-Woods, Bochum University, 1960.



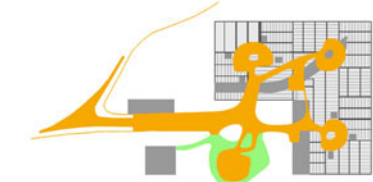
Web. Candylis-Josio-Woods, Center of Frankfurt, 1963.



Grid as nesting on Constantine Doxiadis' work.



Mat structure. Le Corbusier & Julian de la Fuente, Venice Hospital, 1964-6.



Matrix structure. Le Corbusier, Olivetti Center in Rho-Milan, 1962-4.

Fig. 7
 Comparative study of archetypal systems of the Sixties.

ally gain control in the production of geometric shapes and forms, by combining random operations with codified conditions. Additionally, it is possible to parametrically control the structural qualities of geometries, specifically concerning the number of generative curve lines such as Isoparms and Edges, the number of Vertex Points about a curve, the distance between curves, also regularity, repetition, differentiation and noise.

Code Species advanced design studio

The idea of the course stems from the observation that the advancement of the digital tools has often caused to transcend common patterns of computer usage. Specifically, with “tweaking” techniques it is possible to create sophisticated scripts describing complex operations. For almost a decade, scripting has been available in programming languages, having also been relatively easy to access and to learn; moreover, it has been incorporated in various software packages and so it is now accessible to broader user audiences. Scripting is often appointed to gain deeper understanding on systemic development. A set of relationships may first be expressed as text code, which is then translated to geometry, form and space definition. Code-writing is based on algorithmic structure, being about dynamic systems, whose development is dependent upon the geometric / schematic characteristics of their elements and the relationships among them, reductively upon the parameters these elements are influenced by. Such a view was implemented and tested repetitively in a variety of experiments and it has gradually enriched the idea of systemic thinking.

In order to understand the influences of code in systemic thinking, one may follow the early steps that established this logic as a new genre of digital art. The use of systemic logic for creative purposes starts about 10-15 years ago by digital artists such as John Maeda, Joshua Davis, Dextro, Lia and Yugo Nakamura. First versions of scripting were created with existing graphics software including Flash / ActionScript, Director / Lingo, Acrobat / PostScript, Java / JavaScript and were published on the Internet. This sort of creative design was then transferred to architecture through scripting languages embedded in software such as Maya / MEL, Max / MaxScript, Rhinoceros / RhinoScript and AutoCad / AutoLisp.

The use of systemic thinking in architecture may be compared to the quest on archetypical systems during late modernism. Late modern works, being often inspired by the primitive computing techniques that were available at that time, set the background (theoretical and experimental) upon which contemporary research is frequently based.³ Archetypes such as the *stem* and the *grid* and derivative ones such as the *web*, the *mat* and the *matrix* were composed as schematic interpretations of abstract descriptions about space, referring to its structural qualities (Fig. 7). In the last twenty years, compound archetypical systems have been updated according to new design priorities. Contemporary research is oriented towards the advantages of systemic development, by devising compound systems and by applying them in various occasions. With the use of scripting, systems' behavior becomes more dynamic.⁴ Design processes based on dynamic systems are nonrepresentational. They allow direct correspondence between a system, a set of rules, materialization and actualized

formation.⁵ Research is shifting from the selection of fixed structures to the quest of a common logic that unifies the different phases of the design process, being supportive of the interaction among the parameters put to action and the comparative examination of variations. Traditional process gives way to one incorporating perpetual feedback, mutual interaction and exchange.⁶ The result is a more homogenized apprehension of analysis and synthesis, also a more participatory role for the production means, the conceptual tools and the agents of design.

In the course of studying archetypical systems, scripting is applied along with the use of advanced technological equipment, methods and tools. An archetypical system, due to its abstract definition, may be reduced to its constituents and their relationships, then it may be described as a “dynamic machine,” being capable of producing arrays of variations sharing common characteristics. A script may describe the qualitative values and the relationships among agents and parts; even more, it may be applied to dynamic models having adaptive behavior as they function in simulation environments digitally created, also to physical models and prototypes. The related methodologies follow processes of gradual approximation. Overall, the computer is not merely used as a rendering tool of already determined objects, but more importantly as an aid to further explore systemic logic.

Framed by the above observations, *Code Species* studio is organized into the following three phases:

The first phase is about the selection of systems as references, being the “initial ecologies,” upon which dynamic systems will be constructed (Fig. 8). A reference may derive from the natural environment, including ecosystems and geological formations, also from biology, physics, mathematics and geometry; it may also refer to existing architectural systems of space organization. The goal is to define the underlying logic including the relationships among the parts and to depict this logic with the aid of abstract graphemes. Having been stripped from morphological and aesthetic proximities, the system’s structure presents a set of dynamically related qualities, which may be expressed as an algorithmic text code.

The second phase is about the quest on different versions of the initial system, set as variations of the code (Fig. 9). The core code describing the general logic is enriched by more sophisticated parameters, as complexity increases, too. The system is combined with other schemas and responds to agents and forces, as it may gradually disengage from any previous reference. The first versions have to be abstract definitions of the basic principles, upon which more elaborate ones are being built. The idea is to prescribe accurately the system’s special characteristics according to potential scenarios, to which it will adapt. A complex system may be defined by the rules, the exceptions, the forces and the agents causing transformation, also by the basic elements and their combinations.

For the third phase, structure is initially expressed by primitive geometric instances such as lines, curves, surfaces, solids, voids, folds, holes, nodes and joints. An instance is modified consecutively, so that a family of derivative elements sharing common

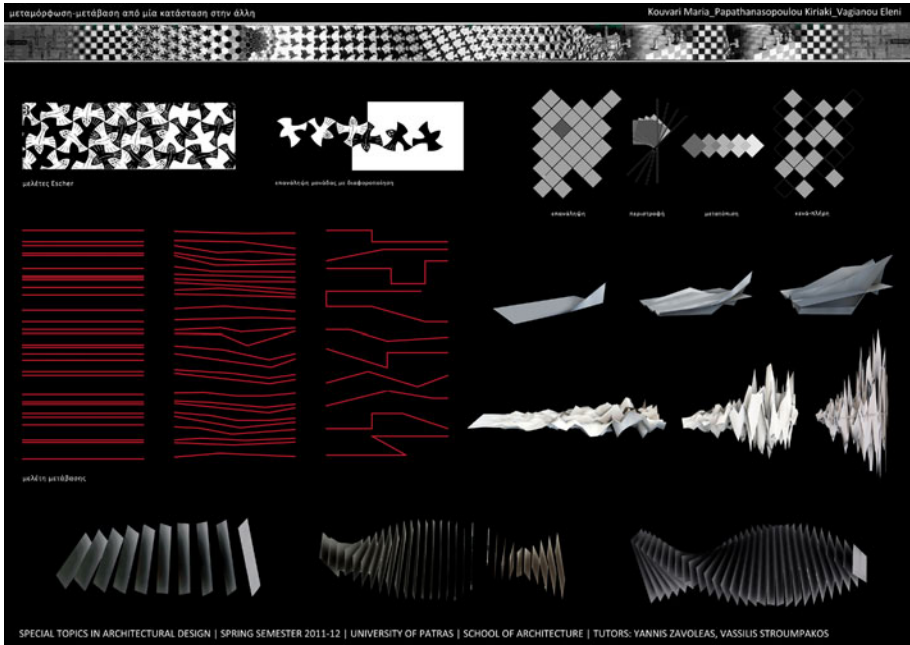


Fig. 8
Quest on system as evolutionary ecology.

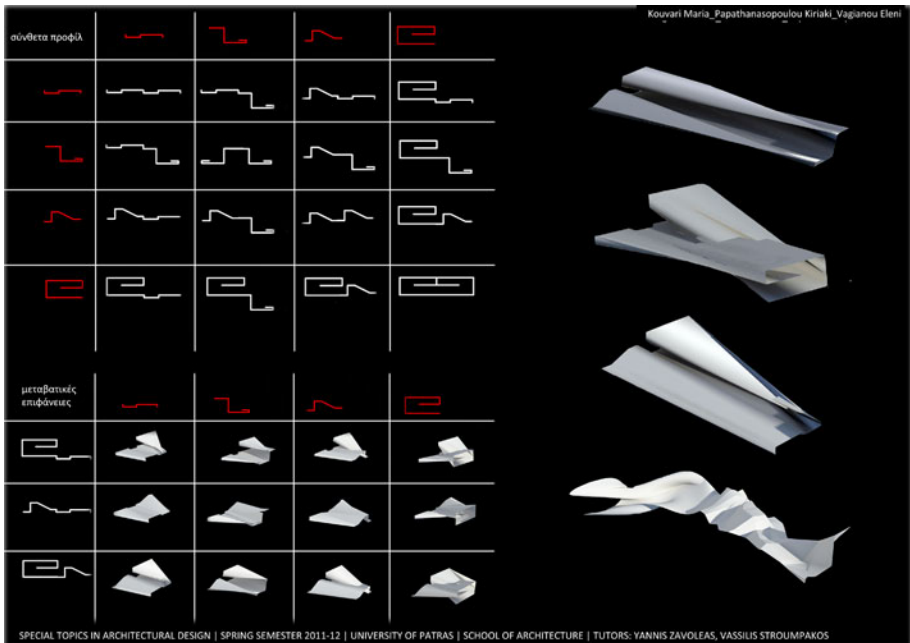


Fig. 9
Dynamic section typologies on compound system.

characteristics will emerge. It is thus critical that the basic geometries are selected carefully according to desired qualities. A criterion for this selection is to compare the similarities between the properties of these geometric instances with those that the final design is expected to have. The system evolves along the process, helping to transpose the set of binary relationships initially set as abstract projections, to the multi-parametric space of the real world.

Research findings

Computer-driven design

As a general estimate, the use of scripting in architecture presumes some expertise in programming, also the ability to adapt code-related operations to architectural purposes. Attempts such as the ones presented above often surpass common computer application patterns, especially those related to practicality and productivity. Overstepping basic assumptions becomes one of the main challenges about scripting, provided that it is used as a creative tool from the start.

In response, special effort is given to present the two courses from a creative standpoint. Starting from a brief introduction of basic commands such as Copy / Paste, Scale and Mirror, the courses embrace soon a more experimental approach (Fig. 10). As the students gradually reach a higher level of familiarity, they become able to evaluate the capabilities opened up by the use of scripting in order to carry out complex

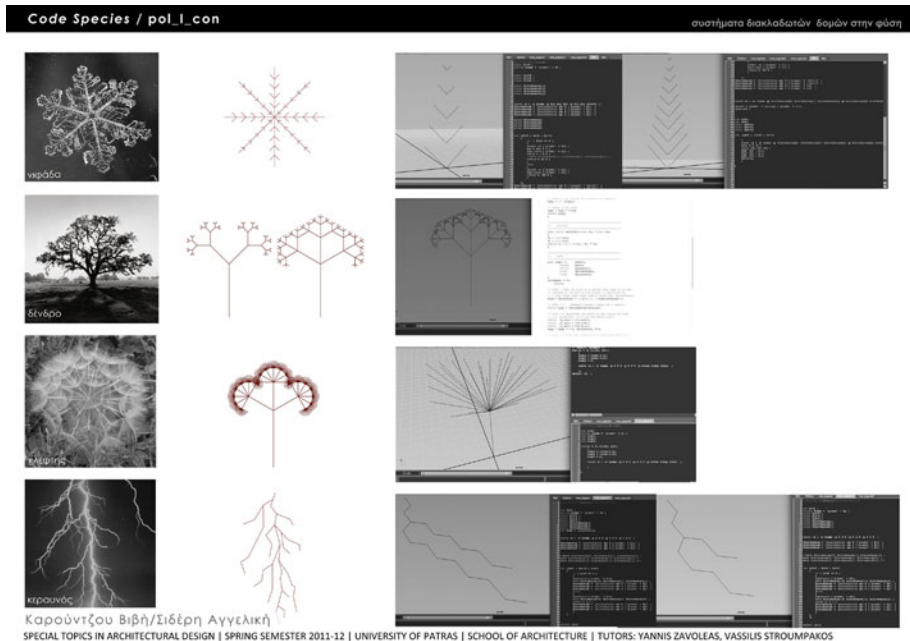


Fig. 9
Scripted experiments using common commands.

operations likely having unpredictable formal outcome. The computer exceeds its function as an “aiding tool” facilitating common tasks⁷ and so a distinction between computer-aided and computer-driven design is necessary. Computer-aided design imitates conventional paper-based methods applied on points and geometries of the Cartesian coordinate system. Then, the transformation to the digital does not add anything new in terms of perception about the object and the processes of its production.⁸ Architectural design falls under the representational logic of two and three dimensions applied on paper and the physical model, rather than under the idea of multi-dimensional space emerging from a set of agents interacting together.

The shift of interest towards computation is due to a conscious effort to relate the active agents of design to the production of form. Design may be viewed as the concrete outcome realized by a series of abstractions, operating on the basis of codes and a complex instrumentality.⁹ Ideally, its sets of values and actions may be organized in the algorithmic code, as more information gradually adds to materiality. In other words, it is suggested that the computer is not simply a drawing tool; it is a computational tool and drawing is an implementation of its capacity to calculate and to compare numbers rapidly and reliably. Such a logic is followed over the two courses, specifically for the conception of space with primitive elements, their relative positioning and associative deformation according to complex conditional operations, as all of them are being conducted by a script.

It is worth noting that scripting processes may further be related to dynamic methods of algorithmic design offered by some of the tools of the software. Advanced procedures related to modeling, animation, particle emissions and simulation dynamics reflect relational properties such as hierarchies and dependencies among objects and their components. They are based on dynamic transformation, rather than on an aesthetic “freezing” of form. The result of such tools is graphic visualizations of intermediate steps of change, upon which scripting techniques may be applied; and vice versa, that is, the visual outcome of scripting is still objects that can directly be modified with design tools offered by the software. From such a collaboration, design can be the result of scripting and design tools combined together.

Conclusion

With computation, form is realized through algorithms of procedures set as rules in response to design priorities. Specific conditions may be viewed as measurable parameters with varying restrictions and ranging values. These parameters take full action as agents influencing design, being codified in the architectural script. The script contains numerical operations for the complex interrelation of any kind of information about material parts, social engagement, shaping form, space and structure.¹⁰ It defines relationships among measurable data and a series of functions applied under specified conditions. The script’s content corresponds to its graphical imprint rendered on the computer screen, producing essentially the architectural drawing. The architectural drawing is thus understood as the visual projection of an assemblage of spatial and material notations representing a series of shared conventions.¹¹ Form becomes a topological system of elements responding to active parameters. It is the outcome of

predefined processes, either as modeling techniques applied directly onto points and geometric entities in the three-dimensional space, or indirectly, as a variety of objects gradually solidifying from abstract to concrete as a work is progressing too, also as a set of forces being dynamically related. Such a definition about form invokes that formal choices and aesthetic assumptions, also typological and structural references, may all be understood as open, dynamic provisions, interacting with the appointed rules, the organizing principles, the abstract schemas and the primitive shape geometries.

Architectural design includes methods, tools, techniques, approaches and theories, also described by parameters and their relationships, being speculative in space and time. Architecture proposes transformations of reality carried out by abstract means of production, such as those of the analogue drawing table and the digital environment, also of code. We are reminded that architecture remains “a complex intellectual labor, carried out with highly specific tools, and yet at the same time, it is never reducible to the catalog of those tools and techniques.”¹² Any of the influences of the computer in the process may be addressed in the transference of action from analog to digital and with the code to the computer’s operational logic. Designing with the computer encompasses all elements and phases of design as active agents represented into the fictitious environment of the screen. The effect of working with the computer is cumulative. Abstraction is not a necessity, but a choice: a relational form of graphics expressed as diagrams, schemas and code-writing, going beyond aesthetic formation and realistic rendering. Scripting methods are especially used to control numerically the agents about a project, also to add objectivity and to increase the dynamic behavior of the produced systems. With code it has become possible to envision architectural design as a process that includes calculations and evolutionary development for the translation of data to form. Hence, architectural design becomes a quest for the special kind of anticipatory flexibility that responds to the participatory role of the agents in the field; it may be described by a polyvalent and directed, yet open and indeterminate, mathematical equation.

Credits

AB-Use workshop

Instructors: Zavoleas, Y., Symeonidou, I., Stroumpakos, V., Pappas, V., Zisimopoulos, D.

Participants: Alexaki, Y., Apostolou, M., Antonopoulos, S., Bounia, K., Christopoulou, K., Galani, M., Kondyli, V., Dimopoulou, F., Dogani, T., Kapsaski, S., Karaïskou, A., Karountzou, V., Kitani, E., Kourakos, G., Kouvari, M., Maltezou, K., Michelis, N., Papanikolaou, I., Petrochilou K., Reppa, P., Sakkouli, D., Siska, K., Spyridonos, E., Svoronos, Th., Tsakalakis, A., Tsatsou, E., Tzemou, K., Tzioras, K., Vagianou, E., Zazani, S., Zombola, Th.

Code Species advanced design studio

Instructors: Zavoleas, Y., Stroumpakos, V.

Participants: Antonopoulos, S., Apostolou, M., Bounia, K., Charitatos, V., Chasa, E., Christopoulou, K., Dalaka, E., Diakrousi, A., Dogani, T., Karountzou, V., Kapsaski, S., Kiritsi, I., Kouvari, M., Kourakos, G., Ksopapa, M., Maltezou, K., Papanikolaou, I., Pasia, E., Papatthanassopoulou, K., Petropoulou, M., Poziou, E., Pourdala, E., Reppa, P., Sideri, A., Tsakalakis, A., Tzioras, K., Vagianou, E.

Notes

- 1 See Allen, S., *Practice: Architecture, Technique and Representation*, New York: Routledge, 2009 (2000), pp. xvii, p. 7.
- 2 AB-Use workshop was repeated at eCAADe 2012 conference *Digital Physicality - Physical Digitality*, Technical University in Prague, 2012. Instructors: Zavoleas, Y., Symeonidou, I.
- 3 See for example Mark Wigley's remarks on the influences of the work of Constantine Doxiadis around the Sixties. Doxiadis introduced notions related to virtual space, or the flow of information, in an attempt to emphasize on the potential of electronics and digital technologies in architecture and urbanism [Wigley, M. "Network Fever" Grey Room 4, Cambridge, MA: Massachusetts Institute of Technology, summer 2001, p. 114. For a detailed analysis on the influences of the research of the Sixties, see Zavoleas, Y., *Machine and Network. Technology as a Metaphor in Architectural Design*, PhD dissertation, Athens: National Technical University of Athens, 2011, part 3].
- 4 Lars Spuybroek further claims that "computing has made every object into a system, and it understands each system to a set of variables, not unlike species or families, and research equates to finding and testing the limits of such test" [Lars Spuybroek, "Foreword," in: *Research & Design. The Architecture of Variation*, Spuybroek L. (ed.), London: Thames & Hudson, 2009, p. 7].
- 5 See also Ali Rahim, "Uniformity and Variability in Architectural Practice," in: *Research & Design. The Architecture of Variation*, Spuybroek L. (ed.), London: Thames & Hudson, 2009, p. 43.
- 6 Rahim, A., "Uniformity and Variability in Architectural Practice," in: *Research & Design. The Architecture of Variation*, Spuybroek L. (ed.), London: Thames & Hudson, 2009, p. 41.
- 7 As Ali Rahim claims, "computers are not used merely as efficient tools to carry out age-old practices; instead, their potential for generating real-time feedback and a more dynamic interactivity between design and users is tapped" [Rahim, A., "Uniformity and Variability in Architectural Practice," in: *Research & Design. The Architecture of Variation*, Spuybroek L. (ed.), London: Thames & Hudson, 2009, p. 41].
- 8 Gabriele Gramelsperger. "Story Telling with Code," in: *Code. Between Operation and Narration*, Gleiniger, A., Vrachliotis, G. (ed.), Basel: BirkHauser, 2010, p. 36.
- 9 See Allen, S., *Practice: Architecture, Technique and Representation*, New York: Routledge, 2009 (2000), p. 75.
- 10 Ahlquist, S. Menges, A., "Introduction. Computational Design Thinking," in: *Computational Design Thinking*, Menges, A., Ahlquist, S. (ed.), West Sussex: Wiley, 2011, p. 11.
- 11 For more on the function of the architectural drawing, see Allen, S., *Practice: Architecture, Technique and Representation*, New York: Routledge, 2009 (2000), pp. 41-5.
- 12 See Allen, S., *Practice: Architecture, Technique and Representation*, New York: Routledge, 2009 (2000), p. 36.

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**Innovative Technologies
for 'Massive' Customization
in Construction Industry**

**Integrated strategies
to bridge the gap**

An introduction to mass customization in construction industry: SWOT analysis

Mass customization is the capability of “producing goods and services to meet individual customer’s needs with near mass production efficiency” (Tseng & Jiao 2001, p. 685) and it can be applied to many production fields.

Mass customization, in an industrial society, can be generally conceived as an evolution of mass production, characterized by the power to personalize goods production while reducing costs and resources use in order to reach high levels of optimization and cost savings.

Since its first appearance and definition in late 80’s attributed to Stan Davis and then to Pine, mass customization has crossed and influenced a lot of production fields (B.J.Pine II, 1993).

One of the latest is construction industry, due to its characteristics: low innovation sector, long term production time (from design to production), often one shot in terms of suppliers involved and contractual agreements. Moreover price assessment by the construction company is sometimes detached by production costs of each supplier (G. Nardi, 1982).

Therefore this sector is often guided by costs more than performance evaluations or innovative technologies, not compulsory in order to reach profits. This is the reason why, while other sectors are pushing innovation and mass customization to face a globalized and competitive market, construction sector suffered from being stuck in a traditional approach.

Nowadays however, the increasing potential of construction industry, due to advanced manufacturing technologies, has raised new opportunities for design.

On the other hand, designers are more and more pushed to personalize their own construction system or technologies, aiming at increasing building performance and quality in general.

Those two trends can look at mass customization as a process able to introduce different degrees of personalization in design without assuming typically high cost of tailor made solutions.

Suppliers in construction industry can take advantages of the availability to change or modify their production chains thanks to CNC machines and tools able of high levels of flexibility.

In order to better understand what really mass customization means in construction industry, we have analysed it through a SWOT analysis, which emphasizes its points of innovation against disadvantages.

This scheme helps to highlight that mass customization in construction industry has high *strengths* in reducing costs of personalized component, in accomplishing architect’s choices and request of variety, and being a driver for innovation from a social, construction and production point of view. Moreover in construction, it doesn’t need any marketing campaign: architecture speaks for itself.

Weaknesses can be seen in an elicitation process which makes it suitable only for some fields/family of component, strictly connected to industrial capabilities (it needs a high flexible production technologies), difficult to control due to the complexity of

Table 1

SWOT analysis of Mass Customization in construction Industry.

Strenght	Weaknesses
<p>Reduced costs of personalized components</p> <p>Accomplishment of architects choices</p> <p>It is a way to satisfy mass demand for variety</p> <p>It's a driver for innovation from a social, construction and production point of view</p> <p>In construction, it doesn't need any marketing campaign</p>	<p>Characterized by an elicitation process which makes it suitable only for some fields/family components</p> <p>Strictly connected to industrial capabilities (it needs a high flexible production technologies)</p> <p>Difficult to control through the complexity of design phase</p> <p>Its result could encounter problem in society acceptance</p>
Opportunities	Threats
<p>Enlarge products range and catalogue</p> <p>Reach a wider market and new market niches</p> <p>Lead innovation in architecture</p> <p>Enhance collaboration between designers and manufactures</p>	<p>If MC strategy is not well prepared it could lead to economic losses</p> <p>People can decide not to pay for a customize product (difficult to conceive the real value)</p> <p>It can be easily overcome by new technologies/needs (necessity to reinvent a company strategy)</p>

design phase and its results could encounter problems of acceptance in the traditional construction chain.

While from the *opportunities* point of view, mass customization in construction industry can enlarge products range and catalogue, reach a wider market range, lead to innovation in architecture and enhance collaboration between designers and manufacturers.

Finally *threats* can be seen if mass customization strategy is not well prepared, leading to economic losses, if customers doesn't see a value in paying for customized product and it can easily be overcome by new technologies/needs.

Zipkin, in his paper "The limits of mass customization" writes about the strategy to be developed by a company (Zipkin, 2001), which should be built around these three inseparable and integrated characteristics:

- *elicitation*: need to interact with the customer in order to obtain specific information;
- *process flexibility*: capability of introducing levels of variation
- *logistics*: good and organized logistic process

This means that only companies are able to face these requirements as a whole, integrating them into their supply and production chain – without losing contact with traditional market and customer – could take economic and strategic advantage from mass customization and personalization.

In construction industry, for example, not all products and components are suitable to be realized and provided in such a way.

Surely, envelope structure and components can be a privileged field of application, as they are one of the systems of major investments because of its representativeness and higher budget allocation.

But even if mass customization in this particular sector is not completely developed like in others, the evolution in information technologies is giving a great impulse to new forms of exchanging informations from the design phase to production phase. New tools and software are bringing in architecture a new freedom of dealing with form but, most important, to deal with the control of informations and data.

In the next paragraph we are going to underline the opportunities of information technologies to bridge the gap and 'inform' design and production.

Information technology as a tool to take advantage of mass customization in construction industry

The last decade has been of great importance in development of a new approach in architecture and construction. Innovative software and applications has given the possibility to designers to experiment fluid forms and shapes increasing the level of complexity of construction.

In the construction phase in fact, most of the technologies to build these complex shapes are ad hoc systems and components, studied by consultants, suppliers or construction firms.

This type of production suits perfectly very special buildings with high value and budget, but is often an impossible path for common and diffused architecture, that is base on catalogues and standard production elements.

Different types of software are now used by designers, like BIM (Building Information Modelling) software, or parametric software which allow a precise control of data and information.

If decided, with those tools, designers can really give at their project the set of informations needed to interface with suppliers and productions machines.

The delicate point is to find the correct informations to pass from one ambient to the other and which of them is useful at the different phases.

The widespread use of software and digital tools among architects and designers is helping the diffusion of personalization in construction, suggesting the possibility to create something peculiar and optimized for specific context or constraints.

As many people from the industrial and design sector highlighted, a way to meet the architectural requirements and industrial production can be the digital or parametric fabrication (Bechthold 2009). It profits by automation tools already well developed and diffused to facilitate the engineering and production of customized components using CNC (Computer Numerical Control) machines and robotic fabrication environment.

This development helped to open new market niches for manufacturer, who could add to traditional supply chain the production answer to the new trend in architecture.

But the problem now is how to diffuse this possibility to exchange information at a wider scale, how to optimise and structure the process in order to exploit all the advantages of customized production and personalization?

In order to understand the strategies and rules of this phenomenon, a research was carried out by our research group, among professionals and manufacturer in the Italian context, in order to give a clear and up to date picture of the actual scenario and future developments. This experimental research was managed by using different tools: through interviews to manufacturers and architectural firms working in the Italian and international context, in order to search for their needs, their objectives in the actual panorama, their productive capacity and future requirements. This research has been funded in 2010 by Milan Province on digitalization and customization of envelope components.

Examples of Mass customization in some manufacturers

In this paragraph we intend to show different ways of using mass customization in two well known construction suppliers in Italy.

They decided to use mass customization in order to face the global economy change, which deeply penalized an already difficult market like construction, while in the meantime to grow new competences and, most of all, to accomplish and follow the future trend of architecture.

The companies analysed thanks to seminars and interviews are both working, even if in different specific field, in the construction segment of envelope and façade components, one of the most dynamic sector of construction as already mentioned.

Permasteelisa is a renowned Italian company born in Italy in 1973 which soon became leader in innovation, engineering and construction of complex architectures all over the world.

After decades spent realizing the most difficult and complex ideas of architects and engineers, which made Permasteelisa one of the greatest companies in the world, the path of innovation diverted to embrace, besides the already established competence, the mass customization directed to diffused architecture.

Before going to analyse the innovative idea Permasteelisa invested on, we need to specify that this company was one the first to dote itself of the



Fig. 1
Section of personalized curtain wall.

most advanced digital tools to develop such complex projects, sometimes borrowing them from other industrial sector, like Catia which came originally for aerospace sector. This advanced position gave Permasteelisa a head start in the customization competition and she became one of the leader in the world for tailor made envelopes.

Going back to the new path, R&D unit of Permasteelisa is currently working on a specific and totally new project to reach a market share which wasn't their target until now, the standardized construction, providing a new system which takes advantage of the big experience in customization and tailoring construction.

The project aims at producing a standard façade component which could be adapted and personalized case to case, in its dimensions, performances or materials, using Permasteelisa knowledge in design to production, skills in software and digital fabrication and, last but not least, the production facilities of the high qualified manufacturing company.

This is a totally new approach to the market which could be considered as a "top down approach", from big and special realities to common and low budget situations, a different way not to be constraint in the same market share and to create new business opportunities, becoming competitor to other types of companies dedicated to this market segment and contributing in the dynamism of the construction industry market itself.

The project is currently under development, after undergoing feasibility studies which has confirmed the maturity of the global market referred to such a proposal, but clearly shows one of the way of development of mass customization.

The other case study is Metra SpA, an Italian company created in 60's that designs, engineers, extrudes and paints aluminium architectural systems.

Besides the common production of Aluminium profiles, systems and windows, which lead in few years Metra to become one of the greatest Italian companies in this field, in the last few years they decided to invest in giving the possibility to engineers, architects and design teams to create their own architecture/components, by introducing a flexible production line able to transform ideas, drawings and studying into new products.

Metra is working both on standardized products, sold through a wide catalogue of aluminium profiles and façade components (mainly directed to small interventions) and customized production.

This last is possible thanks to production facilities Metra is doted with, in particular a special press of 6 tons, the biggest in Europe, where all kinds of profiles can be extruded according to customer's design and need in dimension, complex shapes or application.

Strongly believing in R&D and in providing specialized support to architects and design team as a way to be competitive and to face economy crises, the company created a specific team/laboratory call MAP (Centre of technical assistance to project and contract), where technicians and professionals can follow from the very start until the end a project and develop, together with the client, a special/specific/customized profile or component.

The basis of this approach is to work with the easiest digital environment to maximize collaboration with the design teams and reduce errors or time dedicated to information translations. That means to have many digital platforms and software to

work with according to the ones used by architects and engineers, in order to allow direct exchanges of documents and details.

A third example of mass customization in manufacturers for construction industry is PMA, Parements Metallique Architecture, part of the group Arcelor Mittal, that has given the possibility to several designers to directly interact with CNC machines. Their product are derived from coils of steel and can be tailored at almost the same price of the standard products through the use of milling and pressing machines.

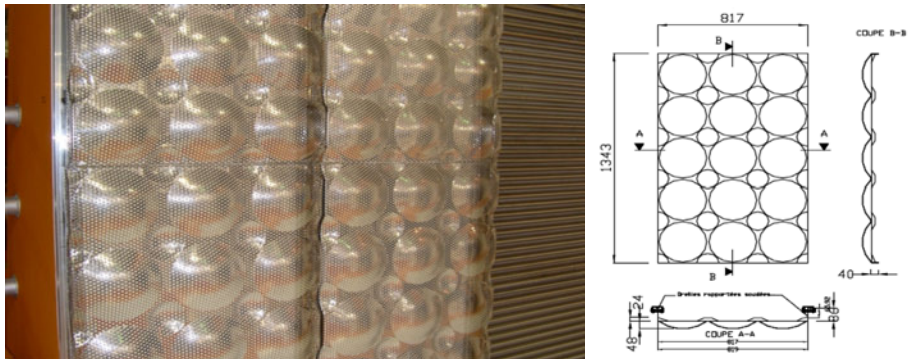


Fig. 2

Examples of customization of steel panels.

The three case studies and their productive approach to customize elements and components for architecture highlight a trend which is common to many other construction companies: the technical support of professionals who follow the design team as early as possible, with the aim of reducing costs and bringing more and more forward the line of economy of scale towards customization.

The experience of architecture firms in personalization

As already subtended, mass customization and personalization of products would not be as diffused and important in construction industry if it wasn't for designers and professionals that can push the market.

In order not to take in consideration just the production point of view in this kind of process, a survey through some medium size architectural firm in northern Italy has been carried out, with the aim to understand their approach to design processes and the necessary relation between them and the construction industry.

Assuming that from an architect's point of view, component design, innovation and customization is largely influenced by the ability to handle software and 2D or 3D design, we asked architecture firms, together with their ambit of research and work, their skills, the professional figures incorporated in the office, the type of work eventually outsourced and, finally, the obstacles to a spread diffusion of such digital design towards the collaboration with industry.

The results, even if not coming from the entire addressed firms, clearly underlined the strong relationship between advanced knowledge of digital tools (like 3D and parametric software) and the tendency to conceive complex shapes or architectures: tendency which lead necessarily to develop customized products and systems.

Although more and more architectural and engineer teams are dealing with this sort of knowledge in order to be up to date and competitive on the global market, it seems that the next passage to producer, who actually make the component design a reality, is lacking of something or is encountering a lot of interface problems.

The survey once again showed that design teams, in the main cases, conceive the digital tool an instrument to obtain and show a certain shape or form, without being able to use the drawing results as the correct interface to shorten the production chain and come up to a practical result (usually demanded to consultants and producers themselves).

This situation can lead to misunderstanding with the manufacturer which should produce the component customized and designed with different software, since many technical information aren't well or enough detailed so that a great effort and work by technical offices of the company is needed to accompany the project to be realized.

In the case of façade or building components, early collaboration is needed between the two parts, in order to incorporate in the project productive constraints coming from machines dimensions/speed/material needs, which only the manufacturer knows, in order to push the design as near as possible to productive limits to enhance customization without increasing too much costs and resources' use.

The moment in which a component design is translated into documents used to build is critical and therefore, the method used to conceive that design and its ability to be an interoperable and adaptive method is crucial to obtain the expected results.

If this method (and its tools) is a prerogative of the design team but it's not interfaced with manufacturer systems and tools, it is possible to loose some information or to need a detailed revision or re-study which means more time and costs to be added to the already different cost of a customization (if compared to standard component production).

The problem is how to reduce the cultural/technical and skill gap that can be present between design team and manufacturer, usually referred to the differences in method.

Starting with the architectural firm, they are usually working with customized production due to the importance of their work, and are now trying to update their own knowledge on 3D design approach to be competitive with other realities, rather than outsourcing to consultants this type of work. This is happening because they are realizing that such design method and tool could help them to save time during creative phases and provide a more collaborative interaction with clients and manufacturers, who understand better their proposal and can easily study the feasibility of each project and building a budget.

The problem encountered is more cultural (difficulty to form people internally without a specific course/input during working hours) and logistic (since 3D modeling for customized components design is not yet widespread, there are only few elements and examples already inserted in databases, like instead 2D elements, which can be easily found or obtained and then inserted into the project and used as a basis for modifications) than technological.

Since the need to spread the information about advantages of 3D modeling to enhance innovation in construction (even in small interventions) is seen as priority, the creation of a database of some elements of the construction could be a new market in

the next years. On the other hand, the consultant agencies – not so many in numbers – whose mission is to translate ideas and heuristic projects into detailed documents, engineering processes and products and optimizing the customization according to market and manufacturers' need, complain the cultural distance of many architects of the "old school" to the potential expressed by advanced design tools: this provide them work on one side, making their support essential, but on the other side rise many risks connected to a difficult technical dialogue on what architects really expect from their components/element/architecture.

Manufacturers and builders, instead, have expressed the need to optimise the process of collecting information on the component and the dialogue with the architect, more than the need to have useful software interfaces or skills to use them. Because, clearly, this is the part of the whole mass customization process with more resources dispersion and costs raise.

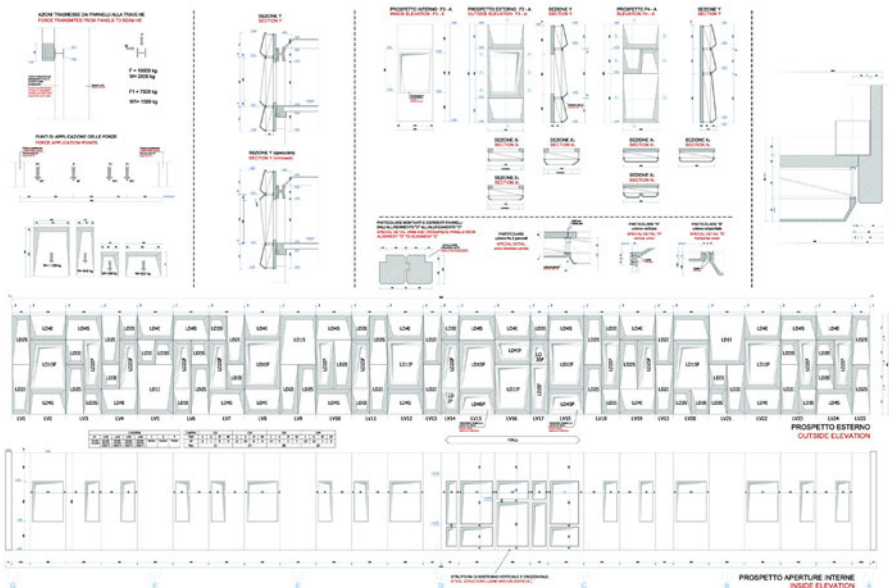


Fig. 3
Noli project: customization of the facade.

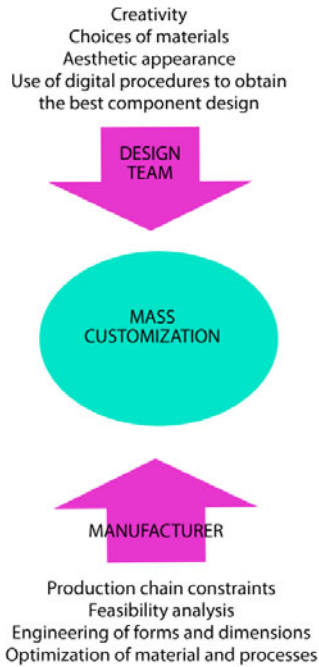
Bridging the gap

Starting from what has been discussed above, we now try to draw some conclusions and give some suggestions for the diffusion of mass customization in construction industry.

One of the obstacle to the diffusion of mass customization can be seen in this difficulty to dialogue between designers and manufactures, due to different responsibilities during the process. The contractual and economic responsibility of a customized component is clearly of the manufacturer, that means that designers can rarely really influence the production.

Table 2

Relation between designer and manufacturer thanks to mass customization process.



ogies, choosing partners able to manage at their best their know how and using mass customization processes seems the way to improve quality while maintaining an edge cut knowledge. This means that innovative technologies developed in a specific context will be easily implemented in different projects, as they have been incorporated in the production processes.

On the basis of the analysis above mentioned, we can foresee, that the future of construction industry and production companies is strictly connected to a new way to conceive the architectural project, highly influenced by software procedures, designer skills and competences, and companies abilities to answer to specific needs also with mass customization.

In this scenario, more and more advanced skills and technical competences will be requested to designers to induce a more profitable collaboration between the parts, more specialized professionals will need to be involved in the project, thus increasing the complexity of the process but also its final overall quality.

This can be changed if we succeed in ‘closing the gap’ between the design, now increasingly using advanced software, and construction process, related to basic contract still very stiff.

Contractual responsibilities is the crucial ring, at the same time strong and weak, of the whole process of ‘information’ of the construction process.

The theme of the collection, accuracy and availability of information is therefore crucial in order to give a package of information that is not excessive for the proposed architecture, either or insufficient to meet the needs of a manufacturer.

It is clear that advanced methods of production are not intended to replace entirely the traditional ones, which for some materials and machining conditions are necessary for proper feasibility work.

However, it is likely to expect that the site will become an increasingly less approximate location of the project construction especially where the constructive methods refers to mass customization.

Moreover construction industry is more and more aware of the strategic importance of technology in the economic competition: acquiring outdoor products and services, adapting technologies,

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Limit-less, Shape-less, Purity-less

**Does the contact with reality damage
the purity and formal expression
of non-standard architecture?**

Framing Computational Process in Digital Tools Evolution

The focus on form control is a recent necessity in the history of computer-assisted drawing, because the initial aim was as a mere saving labor tool. The aim was to replace the drawing-desk with a faster tool, but the design process was left apart from this process and confined on paper & pencil only. Though these processes are a 70's heritage, most of the designers are still strictly bonded to them. This is due to the general approach of aged designers (who are not digital natives) who make most of the building activity today, were used analogical tools through all their professional activity. The aforesaid (old) approach is widely spread and encouraged through most of academic teachings who are more than adverse yet to a basic digital form control through 3d modeling, and completely unaware of the possibilities endowed with computational design tools.

The use of CAD tools went through a series of improvements in managing geometric tridimensional forms improving the workflow, though leaving unchanged the design process. The improvement was pushed to the intrinsic limit of the tools that were not explicitly engineered for architecture. These issues succeed in creating a firm belief, still valid today, that CAD tools are drafting tools, not design tools. This behavior did not change much when free-form modelers have been introduced, changing the base elements from solids to surfaces, which reduced only the form constraints. The freedom to explore any kind of geometric idea with NURBS modeler, though, pushed designer toward new boundaries and new approach to modeling were formed, like Zaha Hadid.

The design environment has changed radically when top-notch architects felt that representation tools had reached the every-possible-shape flexibility, but there was still a gap in constructive feasibility of free-form surfaces. The seamless surfaces that appeared awesome on the screen become ugly panels in reality seemed an un-stoppable barrier to most of the designers. The symbol of this evolution is Frank O. Gehry who was obliged to design the digital tools by himself, applying aeronautical construction criteria to the "discretization" of architectural surfaces. In the same years the pushing of efficiency in drafting and managing architectural building produced the Building Information Modeling. The effect remained limited to optimization of construction process, but it hasn't yet brought the expected revolution to the design process.

In parallel with the evolution of CAD and modeler software, there was the evolution of code languages, though remained a niche area among architectural designer. The customized coding has been a companion of designers since Autolisp language, used from the early Autocad versions, but it was useful for very few designers due to the written text approach. The first step in opening coding to larger group of designers was made by Grasshopper, which is a popular visual coding language, which replaced code lines with graphical icons. Another important example in the area of coding for visual design is Processing, which is an open source programming language built specifically for visual design. Due to the aim of software, the control of newly built shapes has become much easier, but it has created more complex issues.

Before the use of coding software for design, there was a clear separation between the process of form imagination and the one of presentation/refining. The shape for-

mation was controlled firstly by mind-knowledge model then represented/refined with pencil and/or digital tools. The process may imply some degrees of circular reiteration to arrive to the desired shape. The aim of these operations is to succeed in representing shape adherent as much as possible to the one imagined at the beginning of the process. With coding, this process is somewhat reversed. The expected shape doesn't exist. There is a vague idea of some kind of expected results, but the starting effort is definitely not focused on imagining a shape.

The real effort is deconstructing the process of shape generation into a series of possible steps to be coded into a language understandable by machine. At the end of this first phase of coding, the result is draft shape. Once this shape is represented, its control and its editing is not modified directly, but through the modification of code. This process of form-check and code-modification is reiterated until a desired idea of shape is generated. Once the shape, or even a draft shape is generated the computational design opens different ways to complete the task, because all the instruction included in the code are endowed with editable parameters linked to each other. So it is possible to change the link among parameters, or just modify the value of parameters to get slightly different shapes. This operation creates a major issue. Complex and fascinating shapes are very easy to be obtained, so the awareness of controlling them may be lessened, like the feasibility. The unlimited possibility of esthetical expression brings designer to frontiers far from architecture possibilities, both for building skin, and both for interior spaces.

It is important to underline that the freedom of form open by computational design is very useful for creating astonishing building façades, or innovative shapes for roofing and glazing. Computing a façade with algorithmic tools carries a series of advantages, from aesthetics to energetic, from structural to constructive. The step of considering a surface not only as a geometrical entity, but as a materic component gives feedback data to nurture energetic software that correct the building response in respect with solar radiation. The real-time information of the curvature for the single piece in which the facade is discretized provide a good optimization, while minimizing the number of double-curvature panels, and grouping the sets of same panel. While these computational arguments are binding for an architectural building, a wider use of these technologies is possible in all the other fields where an exact array of information on every piece manufactured is not so important. The production of work of art, where creativity is a great resource, can take advantage for this kind of technologies to be spread and developed.

While all the strategies told are manageable for building construction skins or façade, it is less common to achieve such results in designing building interiors. The plan composition, considered as a three-dimensional space arrangement is a much more difficult task to cope with an algorithmic environment, because of all the perception issues implied. The real issue with computational design is to create a symbiosis between the interior and the exterior of a building, making up an architectonical space. This interaction is quite tough to be coded. The composition of a series of living spaces cannot rely only on merging facade with plans. The problem is the presence of structural elements interacting with form, which makes the essence of the architectural shape. Though not completely focused on computational design, few tried to solve this issue; one among them is Gehry, who solved this problem through a strategy. The creation of the facade through a series of esthetical considerations is

completely freed from structural bonds. Structure is added later, only as a support of the external skin of the building, not as a composition element. The skin is subdivided into small surfaces; all of them are linked to the structural system which travel freely from plans.

The whole of these considerations generates a fracture between the use of BIM software and Computational design because they are based on the opposite criteria for shape creation. The BIM starts from a planar element generation, considered as the base from where the shape creation starts. Linking constructive components with geometrical and non-geometrical data creates a system fit for absolute control of construction process, but the scheme is endowed with a strong constraints system, which reduces shape creativity.

Computational design, instead, produces complex shapes easing creativity, but reducing control and calculation. There is a huge effort in computer science community to merge the flexibility of computational design generated shapes with BIM control system, but few results are useful for real-life architecture purposes.

Digital tools and model feasibility

The construction of shapes implies that every surface will be constructed with a materic feature, which will influence the final shape. The facture resistance of a glass being exposed to a certain temperature of operation is a quality that certainly will change the flexibility in curvature of a surface made in that material. So, are all other materic features must be considered essential as a main component when designing a shape for a building. Defining a surface, in computation software, not only as geometry, is a main task to be accomplished when that surface is going to be constructed in a real-scale building. The importance of knowing geometry is, on a reverse approach, information worth to be known. An example of this approach is the study of a façade with a complex geometry. As the single panels of the façade must be precisely evaluated for construction, it is worth to know, since the preliminary design phase, which percentage of the panels will be characterized with single curvature surface and which by double curvature. An optimization of the surface will indicate how to reduce the panel complexity for cheapness reasons.

The scale of construction is an important parameter to be considered. Using a digital tool means always work with a low scale consciousness, sometimes without scale constraints, because the result is visualized in a two dimensions environment, and the model to be built will come into being in a three dimensional environment. Furthermore there is the problem of the limited extent of digital visualization that is limited in the space of the screen. The real life model cannot, in any case, be scaled. Zooming in real life does not produce a scaling, but a detail increasing, proportional to distance from object and point of view.

Computational flexibility is improving architecture?

The possibilities of creating complex shapes has been greatly improved with the computational design approach, because adding intricate hierarchies in architectural geometries is easier with indirect form modification through code. The efficiency of a shape becomes evident only when it is represented, and an optimal representation is

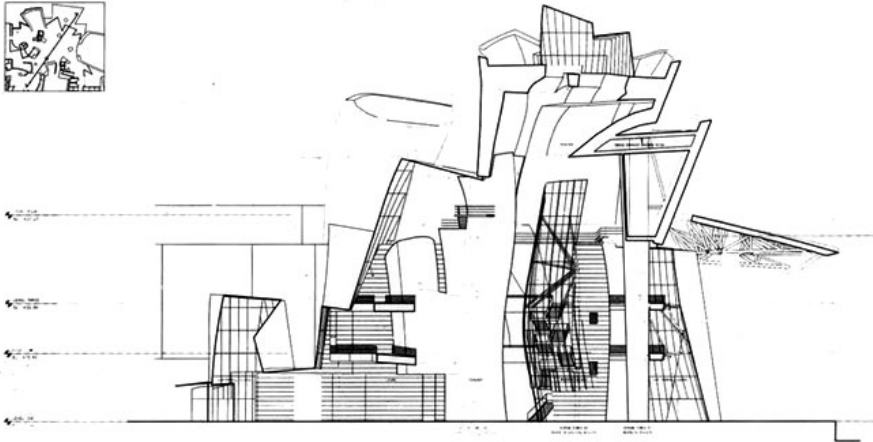


Fig. 1
Guggenheim Museum, Bilbao – Splitting of façade and structure – Section.

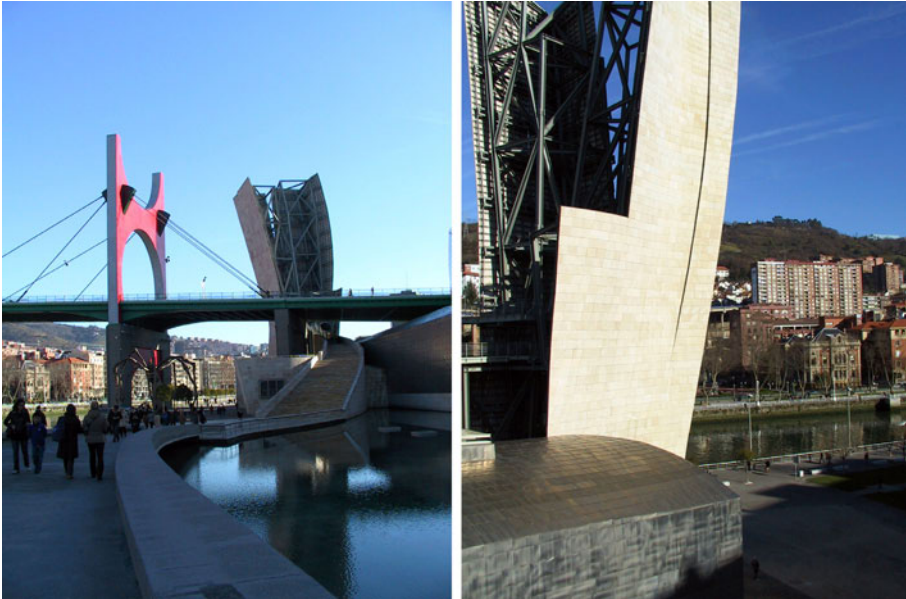


Fig. 2
Guggenheim Museum, Bilbao – Splitting of façade and structure.

derived from the efficiency of a code. The effort for shape optimization risks to be dedicated to the code optimization only, leaving the ornament as the main purpose of design, and the form just as a temporary aspect of a transformation. A real-life building, though temporary by itself, has times of changes much longer than a calculus time, so it is important to give the right importance to things. Furthermore, the wide range of possibilities pushes the designer to prefer complexity to function. Some examples of this tendency are the fascinating snapshots of contemporary works of art that can be

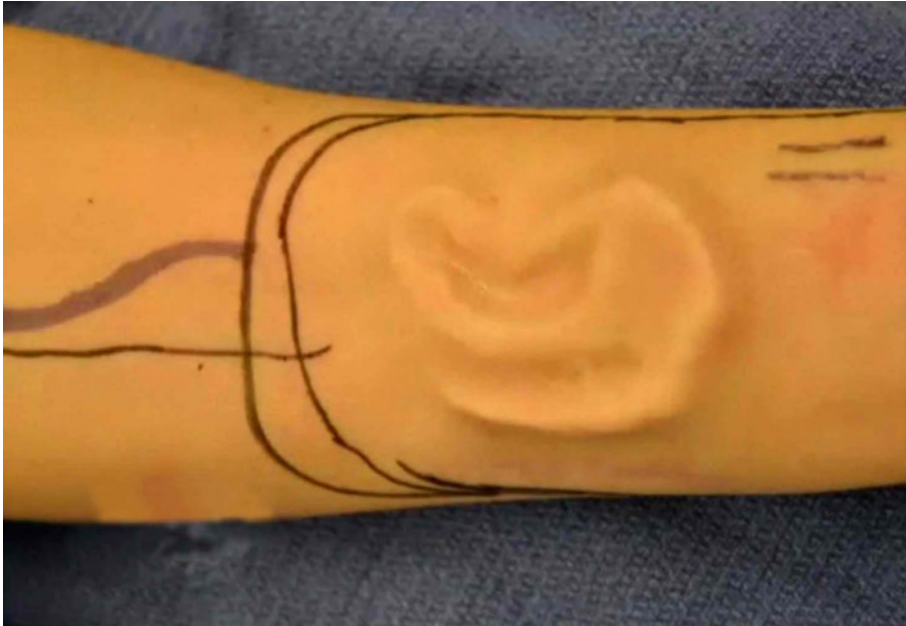


Fig. 3
John Hopkins University – Ear grow under Ms. Walter’s forearm – Dis-harmony of artificial links.

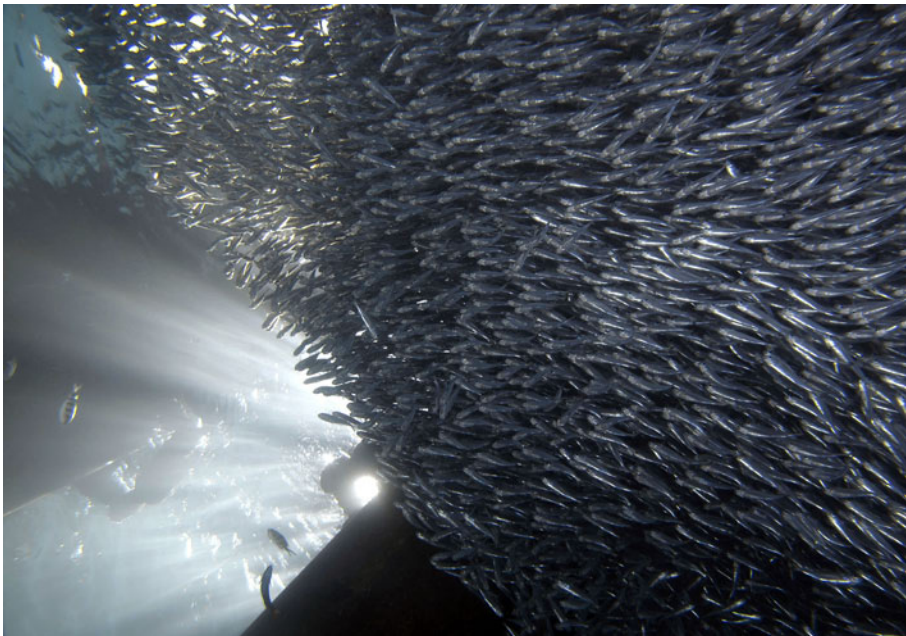


Fig. 4
Bench of anchovies – Harmony of natural system.

adapted to become architecture. So the question is, if this complexity is really a necessity, or it is just a form of temporary fashion¹.

The act of finding of a reason for the form is not a contemporary-only question, but a debate that is affecting the world of architecture since the complexity of building was seen as a feature to be preferred, not as an unnecessary ornament.

Thus, among all possible choice to be coded to generate forms the designer has to choose carefully which to go through. The code as an infinite possibility for creativity should in practice follow some kind of limitations.

*Form (ever) follows function*² was Sullivan's key principle, an inspiring theory for the modernism was one of the boundaries put to the design options in architecture. The historical process that gave origin to modernism in architecture was pushed by the excess of ornament typical of Art- nouveau movement in early 20th century. This tendency brought to the modernism, which Mies' expression "*Less is more*" gave the idea of the good design against the ornament without other function but esthetic.

If we consider the contemporary tendency to over- complexify the shape of building, maybe we are going toward a new inversion in tendency, which will come into being in the near future.

If we consider the functionality as a measure for the efficiency of a form it is not possible to avoid the studies on evolution of natural beings and the ways taken by their changes under the rules of Darwinian exaptation³. Following the natural selection theory, there are no choices among different options, just the extinction of less functional organisms. This approach is carried on through a series of strategies aimed to get the maximum optimization of the resources available. The study of these optimization strategies can be applied to the human need, and goes under the name of biomimicry. Though nature applies non conscious choices, there is a sense of beauty in the results produced after the test of life. All human forms of forcing over natural solutions don't have the inner harmony of natural results. An example of harmony in a system driven by natural rules is a bench of anchovy.

Given a system of particles linked to each other by parametric rules it is possible to establish a relation between nearby elements in a way that the whole system appears as a unique surface. The bank of anchovy, though not following rules of harmony and esthetics results harmonic and esthetically very efficient. it only follows rules of functionality. The bench of fishes swims together for saving energy, for having higher reproduction capabilities and getting a safe haven in case of attack.

The example can be applied to a particle system in a building in which each particle is connected to the neighbors for necessity and parsimony purposes. In the same way, the rules of the computational design must follow necessity criteria, structural and efficiency criteria, so the aesthetics will be a consequence of functions, not a rule by itself.

Notes

1 Del Mese G., '*Progetto e Costruzione/Design and Construction*', Area monographic issue: *Cos-truzione - Construction*, n. 88/2006, pp. 4-9.

2 Sullivan, L. H., "The Tall Office Building Artistically Considered" *Lippincott's Magazine* n.57, 1896 pp. 403-09.

3 Darwin, C., *The origin of species by means of natural selection: or, The preservation of favored races in struggle for life*, John Murray Publisher, 1859.

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Machiel Spaan

Amsterdam Academy of Architecture
The Netherlands

Wicker Shells

Drawing with the material



Fig. 0
Wicker dome, Wicker Workshop, Poland 2012.

Fields of experimentation

For the past five years seven European design colleges have organised an Erasmus IP summer workshop that looks at how a material can generate a form.¹ Each workshop involves examining a particular material for ten days within a specific 'Field of Experimentation'. The process of making is the driving force behind the study. The secrets of the chosen material are discovered through craft and experimentation. Awareness of the material, and of its structure and details, develops through the act of building. A material is therefore not forced to adopt a form. Rather, the form is derived from the material and its properties.

The themes of the conference, 'scaleless-seamless', touch directly the objectives of these workshops. We are looking for the emerging challenges and potentials of (digital) tools in the direction of a more integrated design and construction practice. We are looking for pedagogies that can best ensure the seamless and scaleless in teaching theory to architecture students. We are looking for an architectural education that is engaged with these challenges and potentials.

With the summer workshops we are searching for a 'scaleless and seamless' integration of the designer and the maker. The tool is the material we are working with, and we do not use computers or CAD in the process. "The computer is an indispensable and indisputable tool in designing. The computer is also a fundamentally different tool from the traditional instruments of drawing and methods of making," writes Juhani Pallasmaa in *The Thinking Hand*.² The way in which we can deploy the computer as a tool in the process of design and making is therefore not obvious. Depending on how we wish to shape the relation between the designer and the maker, how we wish to build up knowledge and resources, and how we wish to make students aware of this relation, we can determine why and how we deploy the computer.



Fig. 1
Field of Experimentation, Brick Workshop, Amsterdam, 2008.



Fig. 2
Field of experimentation, Concrete Workshop, Denmark, 2010.

After first explaining the didactics of the Erasmus IP summer workshops, I will then talk in more detail about a number of results from recent years and reflect on the Wicker Workshop held last summer. In the final section I will come back briefly to the possible role of the computer as a tool in designing and making.

The design-by-making workshop

Each year the Field of Experimentation finds another location, in another country and with another material. For ten days all participants are entirely dependent on the material and on one another. What is essential for the Field of Experimentation is that participants can work in a concentrated manner and generate a shared momentum. The participants come from seven European countries, each with its own language and local material. That allows everybody to bring their own experience and expertise to the table, which are then exchanged through the material experiments. Communication is also conducted largely through the vehicle of the structures made. Participants talk through the material and with their hands. During the week, all participants become temporary experts.³

The first days are devoted to experimentation and, together with a 'professional', participants practice what is essential when working with a particular material. Students develop an attitude to and expertise about the material. Material and intuition largely dominate these days. Experimentation occurs in a playful manner, without any pre-conceived ideas about an ultimate aim or concept. They discover the logic of the material and the way in which you can work with it. The process of constantly putting together and taking apart the material turns the exercise into a constant dialogue between design and making.

In the second half of the workshop the experience gained during the initial experiments is translated into intrinsic knowledge. The starting point is not just the material and the method of construction but also a location and an abstract idea about what to make. Playing and testing remain important motives throughout the process, but the focus is on realising an object in a particular place: making a concrete statement.

The workshop offers space for large models and mock-ups. The models are built repeatedly and adapted. You can walk around them, stand back from them, touch them. Material is examined in relation to colour, texture and stacking. Details are put together 'roughly', and the essence and logic of a material is discovered by testing ideas at full scale. This occurs in rapid exercises in which the objects made are presented and reflected upon. The result of this process is a series of solutions that complement one another and tell a story. The repetition leads to a deeper understanding, and that in turn enhances 'professional skill'. At the start the work is dominated by a technically driven approach to the material. By abandoning the rules and habits during the experimentation phase, participants are able to find more uninhibited solutions that are perhaps not 'applicable' immediately, but that teach us something about the logic of a material and the way in which you can use it. This ultimately leads to a design attitude in which the material is not simply a by-product but the guiding element of the design process.

Library of materials and techniques

In 'Style' Gottfried Semper classifies all building materials: "There are four main categories into which raw materials can be classified according to their technical purpose.....on the basis of these four material categories, four main artistic activities can be distinguished inasmuch as they require greater or lesser effort and technical procedures to make the raw material serve a definite purpose suited to its qualification. Accordingly, they can be divided into the following classes: weaving, moulding, carpentry and masonry."⁴

An important aim of every workshop is to find the reciprocal relation, as described by Gottfried Semper, between material and technique. Not only for the students but also for the tutors. A number of architectural themes recur: the floor, the wall, the column, the arch and the roof. They are 'approached' again and again through another material. The key issue is not the shape or the architectural element itself, but the technique with which the shape structured. Each material has properties of its own and a different character. Each material calls for other applications, connections and tools. During the workshop these are sounded out, discovered, and made by hand. Discussion and conversation between the student as designer and maker focuses on how various components can be connected to one another. Sketching with stones, poles, textiles, sheets and branches. Searching for the function, the position and the nature of the connection.

The series of workshops shows that every choice for a particular material leads to particular ways of working, processes and results. A mental library of materials, application possibilities and specific techniques has been built up over the years. Each year a publication of the results is compiled in which the tutors reflect on the process and the work. Gathering together and presenting the results next to one another offers plenty of insight into the particular conditions that the chosen materials set for designing and making.

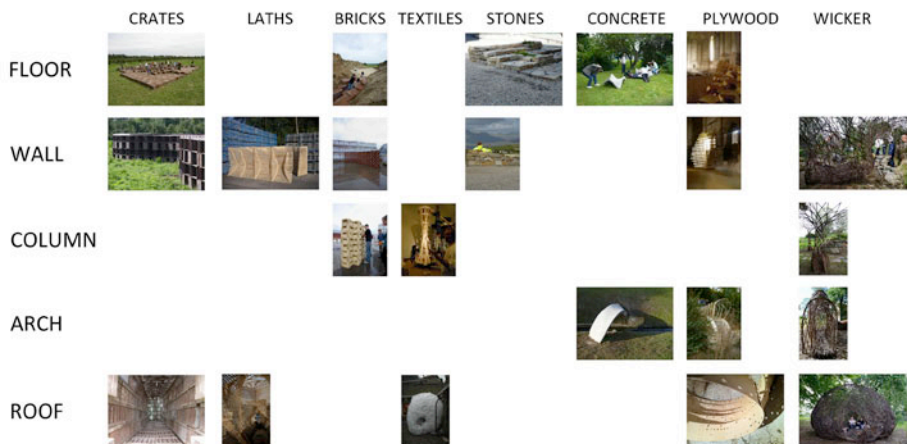


Fig. 3
Library of Materials and architectural themes, 2012.

Brick versus dry stone (masonry)

The difference between working with brick or stone (or a dry stone wall) is great because bricks are identical in form and stones are not. Stacking bricks therefore proceeds very fast, and dry stone walling very slowly. Even so, this slow process is very interesting. Before you start stacking, you first need to divide the stones into categories: which stone can I use where? "It's all about the right selection of a stone.

To find a stone for the gap instead of a gap for the stone. The face and bed are the most important characteristics of the stone. Weight is also important: you should not lift a heavy stone too high. The quality of face and bed and weight determines whether the stone is a foundation stone (heavy, a good bed), a centring stone (no face, but a good bed), a tie stone (a good bed and two faces), a facing stone (one or two faces) or a coping stone (good upper face, not too heavy). The craftsman does this selection by using his experience and his intuition. He selects with his head, hands and heart." This



Fig. 4
Catagorizing the stones, Drystone Workshop, Ireland, 2009.

categorising also comes in handy when stacking bricks. Rapid stacking means that a lot of expertise is lost and we don't look carefully. It is precisely through reading each and every stone and looking at what they can do structurally and in terms of their tactile qualities that we acquire a greater understanding of brick as a material and the stacking of stones.⁵

Plastic and Textiles (weaving and moulding)

In 2009 the Amsterdam Academy of Architecture organised a 10-day workshop with aviation expert Adriaan Beukers and designer and writer Ed van Hinte.⁶ During the workshop the students made spatial structures out of thin, flexible materials such as plastic, tin, textile and paper. It is only through shape and in combination with one another that such materials acquire the 'sturdiness' that is needed for construction. Through this method of working, the more standard design procedure — extending from programme and shape to an elaboration in materials and details — is reversed. This resulted in new, lightweight and progressive solutions. Form and texture emerged from the properties and qualities discovered in the materials used. Thinking on the basis of techniques of form and combining materials generated new insight into the design of structures.

A group of students worked for a week with plastic garbage bags. Filling them with air and sealing them produced a construction material. The students then went about finding the right way to tie these 'inflated' bags to one another. They discovered that there are three types of connections and that each connection requires its own 'knot'. Once this discovery had been made, students could build in a very precise manner.



Fig. 5
Weaving and Moulding, Thin City Workshop, Amsterdam, 2008.

Another group worked with textile and used glue to stiffen the textile. The students discovered that warping and stretching the material created pleats in the textile, which made the structure stiff and sturdy. This made it possible to construct a column of fabric. The students developed a 'rotating machine' with which they could warp a column in a controlled manner. The machine is an extension of the hand and makes it possible to carry out the warping process extremely accurately. (We also saw this principle of warping at work in the wicker columns.)

In the aviation industry people are constantly looking for light and strong structures. For aircraft constructor Adriaan Beukers, these unrestricted studies are essential in advancing beyond the existing conventions in order to discover new applications of materials and techniques.

Joinery (carpentry and weaving)

The Erasmus Summer Workshop 'Wood' focused on a number of basic principles of the craft of joinery. Pieces of timber are limited in size. That means that joinery must always be involved when timber components are extended, widened, crossed or turn a corner.⁷

The sequence in which the different components are assembled is of the utmost importance when erecting a structure on site. This has a lot to do with the structural



Fig. 6
Joinery, Plywood Workshop, Belgium, 2011.

and engineering hierarchy of the different pieces with respect to one another. In the shipbuilding industry, for example, the different timber pieces of the ship serve different structural purposes depending on their arrangement. By analogy with the human body, the keel is the spine, the trusses are the ribs, and the planks are the skin. We see a similar hierarchy in a number of the objects made.

The different pieces of timber are connected to one another by new timber joints. Each part of the object has its own function and meaning. The combination of the right joint and the right technical and structural application of the different parts can lead to an ingenious object in which form, function and technique come together. Synergy between appearance, material and structure results when the structure, building technique and formal character reinforce one another. The different parts meld together to form a new configuration in which all elements find their logical place. This results in an object with a self-evident arrangement.

To an architectural scale

After brick, dry-stone walling, concrete and plywood, the summer of 2012 focused on experimenting and building with wicker. The wicker weaving technique is associated with the traditional manufacturing of small utilitarian objects. This technique, practised in Poland for centuries, stands out for its potential to build complex and resistant shapes thanks to the flexibility of the fibre and rigidity provided by the weaving.



Fig. 7
To an architectural scale, Wicker Workshop, Poland, 2012.

Wicker has traditionally been used for weaving baskets and bowls. In addition, when woven into mats, the material serves as 'reinforcement' for dikes.

During the first two days of the workshop the technique of wicker weaving was explored and practised. After that, the students made architectural structures out of wicker. They developed various technical strategies to translate the scale of the object into an architectural scale. Based on these properties, our workshop explored the manufacturing of the weave in relation to landscape and architecture. We explored the potential of a natural raw material and an ancient technique of patrimonial nature, aimed at new use options and on a large scale. In the introduction of the publication 'Making Architecture' Andrea Deplazes makes us aware of the importance of the architectural scale: "In the end, however, architecture only exists when it has become physical, when a social program has become an architectural project, and from that, in turn a material and spatial object. At issue here is the transfer of a thought, a concept, into built architecture. At this moment, everything depends on whether this transfer occurs plausibly, meaningfully and completely. That precisely is the issue when architecture becomes physical creation."⁸

Is there a close relation between concept and materialisation, between idea and construction through the use of an obviously 'natural' material like wicker? While at the scale of objects the result of the weaving is rigid and therefore resistant to compressive strength, at the scale of architecture, these surfaces tend towards flexibility, which makes them resistant to stretching. The opposition of material behaviour between the two scales creates differences in the design and construction process of the weaves. In order to create stiffness and stability without another material, the weave of the single wicker might be reflected at a larger scale in the formal design as well in a process of layering. The thickness of the wicker fibre, the geometry that arranges the weave, the way it is structured and the handmade technique, are the variables that determine the properties of this weave and its possibilities, and give us the design tools for a performance of the material according to use and scale.⁹

Weaving easily produces rounded forms owing to the properties of the material and the technique applied. The process of weaving depends largely on the flexibility of the material. That allows forces to be absorbed by the structure through 'pre-stressing'. The curved wicker wants to 'return' to a straight position, and the resulting force released lends the woven structure its strength. This makes it difficult to coerce wicker into a particular form. Instead, the form emerges partly through the process of twining strands. You can guide this process to some extent, but in the end the power of the material determines the curvature and, hence, the form.

In scaling up the basket to an architectural structure, one must rediscover the technique of weaving, as has been stated. Wicker lends itself extremely well to making curved surfaces and arched sheet structures. These curved shapes help in making large spans. Adding tension to the material makes surfaces strong and sturdy. This can be done in different ways. A prefabricated plane can be bent into a shape. But tension can be introduced into a structure right from the start. During the wicker workshop

the students tested a range of weaving and knotting techniques in order to make the jump in scale.

A dome. How do you make a round shape if the wicker does not let itself be coerced into a shape. The first efforts in making a spherical shape always led to impure egg-shaped objects. Inspired by Leonardo's dome made a year earlier, the students started weaving the dome from the centre. As a result, the form emerged of its own accord on the basis of the weaving method. The structure is a 'randomly' woven surface. Adding tension to this structure results in a sturdy rounded shape because the curved wicker branches press inwards. Weaving in a controlled manner results in a geometric shape, a nest for about fifteen people.

A column. A tall structure becomes unstable very quickly. During the experiment a model emerged in which the wicker is woven, not straight up but warped into a column in such a way that triangles are created. Weaving the wicker at the intersections of the wicker branches into planes produces fixed-moment connections. These, in combination with the triangles, produce a sturdy structure that can easily reach a height of three metres. Making the knots very accurately results in columns with an industrial and organic character.

An arch. As the object increases in size, you need more material to maintain its strength. One way of achieving this is by grouping a number of branches together to



Fig. 8
Wicker Dome, Wicker Workshop, Poland, 2012.



Fig. 9
Wicker Column, Wicker Workshop, Poland,
2012.



Fig. 10
Wicker Arch, Wicker Workshop, Poland,
2012.

form wider lengths. The students in this group developed a method of 'extending' the grouped branches. This enabled the creation of a construction taller than the 1.5-metre length of the wicker branch. Further development of this weaving technique ultimately led to an object with an arched interior space you could stand up in, but the object is also so strong that a number of people could sit on it.

Wicker is thin and flexible and can take on various shapes. The thin side of wicker can even be knotted. Wicker connections are often derived from techniques of weaving and knotting. In these textile connections the hierarchy between the various parts of the structure is often less clear than with the plywood structures described earlier. In the dome constructed, each branch of wicker is technically equal. Even so, the right sequence of adding each strand is essential in achieving the intended result. All wicker branches are also equal in the arch constructed, even though they join to form bundles in many places to create a stronger connection. Here we can already see something of the hierarchy that we already saw in the plywood arch structure. In the column we can still see an architectural hierarchy. We can still recognise clearly different structural elements. Becoming aware of this order, or precisely the lack of any order, is an important discovery and helps the student to establish the relation between the technique of making and the appearance of the design. Every decision in the process of making influences the appearance. Understanding the structure, the construction and the junction ensures that the process of designing and making becomes more precise, more discussible and more negotiable.

In this way, the studies of 'rounded' and folded forms do not emerge on the basis of an image defined in advance, nor on the basis of a computer exercise. Rather, the forms appear as one sketches with the material in the hand. The resistance of the material allows the maker to sense the shape the form wants to adopt. This gives the builder a physical awareness of the relation between material, structure and form. As a result, a vocabulary of forms we are familiar with from the computer-generated blobs and folds now becomes tangible, tactile and directly experienced at the human scale.

Drawing with the material

By experimenting with various materials, the Erasmus IP Workshops raise awareness among the students and tutors about the reciprocal relation between designing and making. This awareness is fed by repetition, intuition and reflection. The focus of all exercises is to foster an attitude of research and reflection in relation to designing and making. The material and the possibilities of applying it are the chief concerns in this process. Can the computer act as a supporting tool here?

In *The Craftsman*, Richard Sennett writes in a section entitled 'Torn skills' about the complexity of Computer Aided Design. In addition to its qualities, Sennett lists the possible limitations of the computer in the creative process: the static and purposeful method of designing with the computer. Sennett quotes Renzo Piano, who talks about repetition and practice: "This is very typical of the approach of the craftsman. You think and you do at the same time. You draw and you make. Drawing... is revisited. You do it, you redo it, and you redo it again".¹⁰ Sennett observes that the binding



Fig. 11
Drawing with the material Wicker Workshop, Poland, 2012.

circular metamorphosis described by Piano is disconnected by the computer. If the computer is to fulfil a meaningful role in this cyclical process, then it will have to be able to integrate the circular movement into the CAD process. At the end of his essay, Sennett describes the role of drawing in design. You can also read 'making' here instead of 'drawing': "The tactile, the relational and the incomplete are physical experiences that occur in the act of drawing [or making]. Drawing [or making] stands for a larger range of experiences, such as the way of writing that embraces editing and rewriting, or of playing music to explore again and again the puzzling qualities of a particular chord".¹¹

That brings me back to the question posed at the start of this symposium: how can we deploy the computer to enhance awareness among students of the relation between design and construction? How do we connect the designer and the maker? The combined 'CAD drawing' is just one possible connection between the two. This drawing lacks the genuine experience of gravity. The drawing lacks the resistance of the curved wicker, the sense of the tool, the feeling as the thumb guides the curving of the wicker, the experience of the object that shapes itself of its own accord. The CAD drawing does not permit intuitive actions such as these. The computer model is static and does not allow itself to be adapted easily.

Herein lies the challenge presented by the computer and CAD as a tool that can bring about an intelligent interaction between design and construction. How can the computer make the drawing less static? A drawing as a fluid open product that offers space for experimentation, space to admit intuition and space for the designer and maker to embark on an interactive game to discover, refine and execute innovative architecture. The drawing as a space, and a field, of experimentation.

For me, the direct relation between hand, head and material still remains essential in connecting the designer and the maker in a meaningful way.

Notes

- 1 IP Erasmus Summerworkshop, 2007 - 2012, Coordinator: University of Liechtenstein, Vaduz. Participants: Gdansk University of Technology, Faculty of Architecture; Sint-Lucas School of Architecture, Belgium; Royal Danish Academy of Fine Arts, School of Architecture, Copenhagen; Academy of Architecture, Amsterdam; Norwegian University of Science and Technology, Trondheim, Faculty of Architecture; University of Liechtenstein, Vaduz; Universitat Polytècnica de Catalunya, School of Architecture of El Vallès, Barcelona; University College Dublin, school of architecture, Ireland; University of Ljubljana, Faculty of architecture, Slovenia.
- 2 *The Thinking Hand*, Juhani Pallasmaa, 2009.
- 3 *A Temporary Expert*, Machiel Spaan, Jan Peter Wingender, 2006.
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**Building Performance
and Fabrication Performativity
of the Seamless
and the Scaleless
in the Exhibition Space**

The phenomenon and the question

The design and construction of an indoor exhibition space is an issue that has many aspects, amenable much and dynamic resolution. Changes in organization and orientation of an exhibition space often exceed the ability of adaptability and flexibility of the space itself. Most of the times the exhibition space follows progress. In this paper, an underlying assumption is being made; the exhibition space can be either commercial or cultural use. In both cases, the key demand in the design and construction is the communication between the user and the exhibit as part of a performance, i.e. within the definition of scenarios of interactive user and space activation

Contradictory to the Creation process parameters

In this chapter we present a series of observations on the ideological, cultural and operational practices of an exhibition space, highlighting the importance and relevance of the problem and lay the foundation for further exploration of the creative process in design and operation of exhibition space.

The museum as a place of systematic classification and exhibition. Systems of Knowledge and Control. Cognitive systems, relations of power and space

In the introduction of Foucault's book "The Order of Things: An Archaeology of the Human Sciences" [6] the story of the "same" with the story of "order" of things is connected, wanting to highlight the consequences and the power of classification systems. The composition of exhibition and artifacts classification systems appear to have a decisive role in transmitting particular socially predefined knowledge in museums and exhibition spaces. On the other hand, the digital cultural content databases have penetrated in museums warehouses without requiring in advance established classification perceptions, but in the contrary they create open lists of organization content.

Artifacts Identity

The Artifacts Identity, from the moment they are moved from the warehouse to the exhibition space, is granted. Even if it is suspected that they conceal multiple hidden meanings, this is not obvious to the visitor. Additionally, in industrial design, in the field of human-computer interaction, researches already in progress are examining multiple modes of recruitment and production of digital cultural content by the same user-visitor, shifting the focus from exhibition to the interaction

Subdivisions and arrangements of objects and space. Crewing policy

Following the previous observation, new collections require new museum experts, new research, new organization of the exhibition, new arrangements of artifacts in space and among each other, new subdivision of the space, new space. At the same time sensors and actuators are being adjusted to the materiality of construction, to produce intelligent environments that respond to requests such as extensibility, re-settlement and re-interpretation of space.

The location of Artifacts in museums and the context in which they operate

The interpretation that one artifact can accept, does not concern only the research progress, but also the context in which every museum wants it to be incorporated. For example, an archaeological artifact of daily use that can in a museum of decorative arts belong to a category and be exposed in the specific group of artifacts, in a museum of ancient technology or a Museum for Materials could belong to another category. At the same time, technological platforms which include “lists” of Museums aiming co-collections and -exhibitions of inter-connected artifacts are available to the public.

Format Axis: subject - object - space

According to the basic distinction between ‘public’ and non-public use of artifacts, people are classified into general categories of “visitors” and “museum experts”. Even when talking about “public expansion”, this basic distinction is not affected.

As for the precise meaning or the significance of the collection, is of the sole responsibility of the museum experts, since guests are generally limited to observe the collections as they are presented, and therefore any interactive element between public and artifacts is absent (Hooper, 2006). On the other hand, during software development in user-centered design, several fictional Personas are created to represent the archetypal end users. Especially in museums digital educational programs, issues of personalized visit and digital information production from visitors aiming to their active participation, are being examined.

Case studies

The example of Museum exhibition space. The project is located in the municipal district of Crete, Kissamos. It is about the design of a musicians museum in an existing building which was originally a school. The study involved the following disciplines: architects, civil engineers, mechanical engineers, musicologists and museologists,



Fig. 1
Museum - existing building.

who determined in advance the design requirements. The study is in the preliminary design stage and therefore the cost parameter is not specified because all the methods and the materials of construction are not in detail resolved. Also, the importance of the project and the role it would play in the region has not been determined. There is no answer to questions such as, whether the museum would provide a powerful local or global hub. There are still a number of research questions related to the content which would remain open even after the creation of the museum, such as: the musicalogical research in progress, the museum's material which is enriched and reshaped by new interpretations. Finally, basic parameter of change is the rapid replacement of computer systems - artifacts used in exhibition spaces.

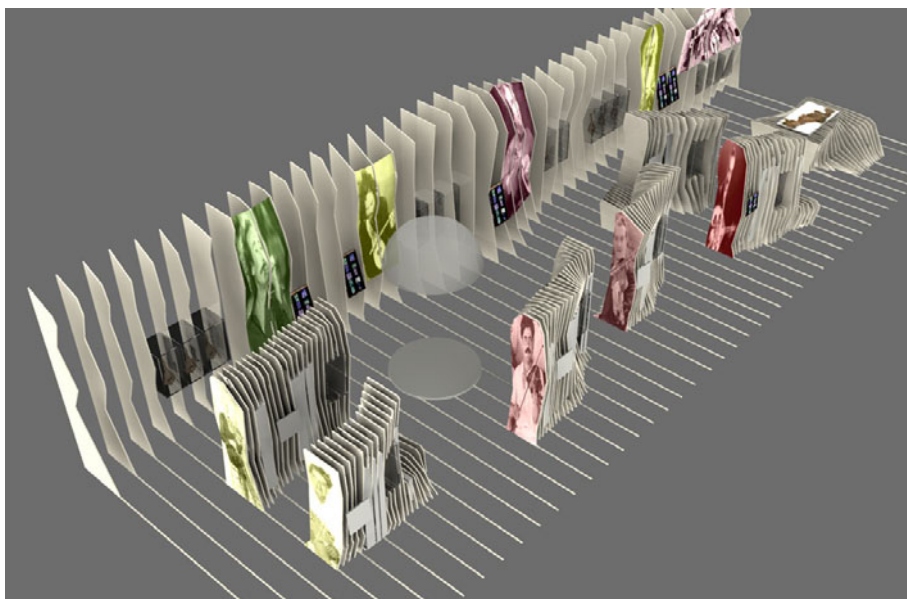


Fig. 2

Museum – exhibition space.

The example of shop exhibition space. The project is located in Kolonaki, one of the most commercial areas in the center of Athens. It is about the interior design of a jewelry store. The store has a total area of 40 sqm and its dimensions are 4x10. The small dimension is on hand of the road and is the entrance and the shop window. In the basic design intentions was that the shop would be a landmark for the area, have a kind of recognizable corporate identity, be able to be repeated and adapted to other places that are not known in advance, keep construction costs at relatively low levels and have a fast construction time, be able to exhibit, present and store quantities and types of products that are not predefined and finally to be able to change seasonally the way of exhibition and promotion of the same products. Reaching the construction stage a large number of parameters are added, such as material selection and construction dimensioning and how all these connect - nodes of materials. Finally, the mechanisms of the mobile parts of the constructions and the possibilities of use they offer have created another category of parameters.

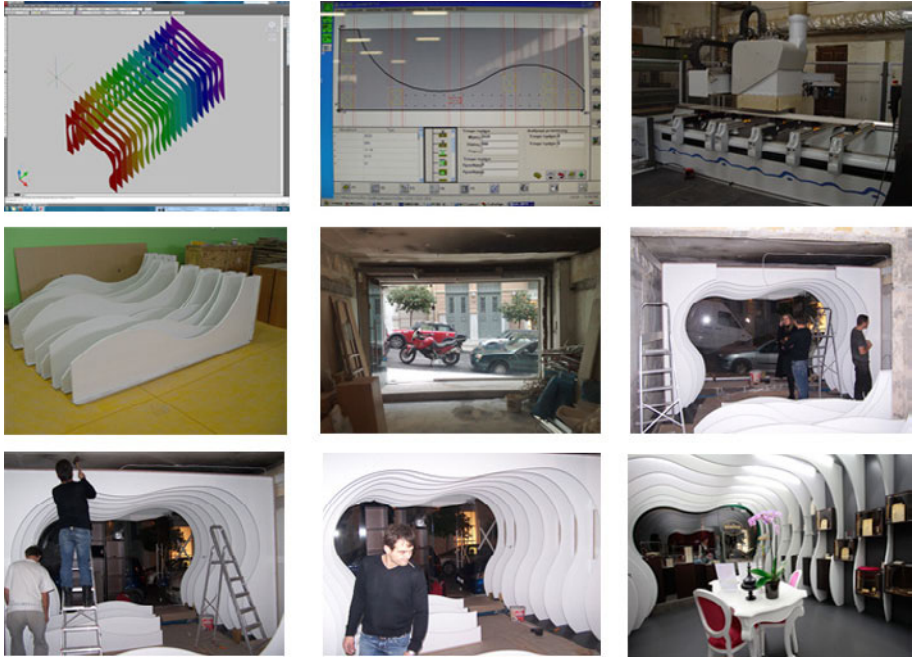


Fig. 3
From design to construction.



Fig. 4
Shop - exhibition space.

Methodological tools

Through the description of two specific case studies, an attempt to record and classify the parameters and values arising on the design and construction of exhibition spaces, is being made. It is considered, that there is a continuum of design and construction in delimiting the parameters and their values. This paper examines specific case studies in order to identify specific parameters required that the architectural design is called to solve. The initial overall classification uses the logic of the traditional fragmented structure and organization modules.

Axes that define the design parameters

- Holistic approach, involving many disciplines
- Many successive stages of study, admission of the factor of time and cost in the study
- Physical limits of the existing space and objects
- Scenarios activating user and space

Axes that define construction parameters

- Materials and dimensions
- Connection modes – hubs
- Mechanisms and their potential

Thoughts towards an holistic, scaleless and seamless thinking about the operation, the form and the materiality

The above parameters are met through design solutions but actually have limited boundaries. Alongside the design solutions seek to abolish limits or produce bottom up solutions without necessarily the designer to be able to control the outcome other than the user. One of the key directions for future research is the creation of software that can provide a single web platform for collaboration of all involved disciplines.

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Interactive Fields

**A Reciprocal Situated
Design Knowledge**

Introduction

*"Natural ecosystems have complex biological structures: they recycle their materials, permit change and adaptation, and make efficient use of ambient energy."*¹

John Frazer

When Frazer made this statement, it was perhaps an interesting counter-argument to the existing ideas of the architecture at the time. In his statement he was questioning the already entrenched architecture of stasis. From the earliest treatises on designing buildings until today, this field seems to have developed a gap between its educational system and its practice. By constantly revising and questioning the firmly and securely established concepts from the subject of study to the act of practice, one is able to discover dormant design possibilities and revive architectural parts that render the discipline more unified and complete.

This paper will present how embracing the concept of always re-examining and questioning basic architectural attributes can strengthen the practice, especially when this is applied at an early stage; at the educational system. By revisiting the process of teaching, one should overcome the fragmentation from training to practice by analyzing design "dead-ends" and forming questions of constructive critique and understanding the world we live in.

In a time of amplified social interaction and an increased focus on issues of connectivity, adjustability and dynamic relations, there is a need for our built environment to evolve beyond its current relatively static state. The structures of a society that is expressive of its rapidly developing technological culture need to surpass the condition of motionless balance and embody in the design forms of motion and action. The concept of motion in architecture suggests a type of design in which "conversation" between the user and the built space is enabled. This paper focuses on how ideas and projects from the past can inform current designs to allow these various "conversations" to occur in both theory and reality.

By definition, Architecture can mean the style and method of design and fabrication of physical structures but most importantly it reflects the technological and socio-

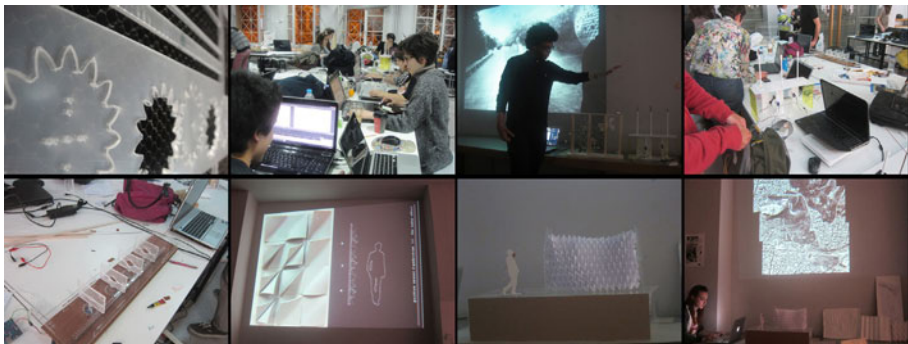


Fig. 1

Concurrent architectural technology – AA Athens.



Fig. 2

Digital design realization via machinic fabrication – AA DLab London.

economical circumstances of their time. As such, technological advances in fields outside architecture like aircraft and automobile industries, biological and computer science have been shaping the design discipline ever more actively for the past 50 years. Already since the 1960's, influential architects such as the Archigram and the Metabolists began expressing ideas for an architecture of change; an architecture that has the ability to meet the changing needs in regards to evolving individual, social and environmental conditions. Their vision of what the future architectural world might be is not necessarily one with always fixed roots to its ground but one that is flexible and adaptable in time. According to them, Architecture is a practice that needs constant rethinking and revisiting of its application methods. Through their proposals they managed to stimulate alternative thoughts and questions in the discipline.

Have you ever thought of living in a three-dimensional grid-like city where your dwelling can be dismantled and moved? Have you ever thought of spending hours daily in an artificial bubble suspended from the ceiling while communicating through monitoring systems? These questions were perhaps more provocative at the time they were expressed through manifestos of different architects of the 1960's. Nevertheless, by understanding the way by which these questions have affected and still are affecting the course of architecture will enable us to express thoughts which in turn are going to influence the future course of the discipline. The key element is to always keep "mobile". Once again, the advances in technology suggest that adaptation offers a more practical way to a system's sustainability. The architectural system of education being unable to aim at architecture's relationship to contemporary social and political disorders is a field in need to be revised.



Fig. 3
Biodiversity clusters' kinetic reactive structure – AA Athens.

Starting by questioning the educational system, this paper presents the work of the Architectural Association Visiting School in London, Istanbul and Athens. Launched by the AA School of Architecture in January 2008, the AA Visiting School is a unique learning model, which is based on combining the highly focused agendas and interests of small design units with a prominent public program, audience and outside visitor participation. The AA Visiting School for these three International Cities is a pure example of a system that is realigning and reconfiguring itself, able to invent a new, elastic 21st century, interconnected infrastructure at a global scale. In their fundamental form, these specific AA Visiting Schools are questioning the relationship between the tutors and the students, they are redefining the teaching environment, and they are revising what would allow for a smoother and seamless transition from the academic to the professional life.

Faculty and Students

*"I know one thing, that I know nothing"*²
Socrates c. 469/470-399 BC

In the field of education, the concept followed in the AA Visiting Schools in Athens, Istanbul and London is that instructors and students are engaging together the task in-hand; the given architectural problematic is approached by the active learning technique. With this approach the participants or students are as equally responsible for



Fig. 4
Digital fabricated prototype family – AA Dlab London.

learning as their tutors are responsible for disseminating the knowledge. In contrast with several institutions, the student is placed in the center of focus and experiences an intense and complete method of learning by undergoing several different activities simultaneously.

One of the main activities by which the AA Athens, Istanbul and London Visiting Schools carry forward their architectural agendas is by introducing design techniques and themes through a team-based workshop approach. Design teams in different units are emphasizing on creating proposals through a collaborative setup. In this way, there is a variety of different material for different classes. The students are able to approach the problematic through different options and therefore the end-results often tend to be quite diverse but with the same direction. In general, the students are initially exposed to video recordings and film presentations as alternative presentation modes which allows for smoother, seamless and more effective method of communicating the topics under discussion. Throughout the duration of these Schools, the tutoring team plays its' role in a specific way; the number of tutors in proportion with the number of participants is 1 to 5 as the goal is to provide tutorship equally. Essentially, the tutoring team becomes part of the student body. At first, the instructors propagate fundamental design techniques and theories to the students. Then they participate as if team-mates to the teams they supervise in order to provide solutions for the given task together with them and always with a line of reasoning. In contrast with trying to impress or persuade the students to accept the tutors' point of view,

these AA Visiting Schools implement an approach similar to the Socratic Method. Also known as the method of elenchus, it is a form of debate where individuals with different point of views are stimulating their critical thinking through a series of questions and answers. Throughout the tutorials, the participants are often asked questions in the methodology being applied at the time in order to generate reasonable and reflective thinking. Rather than just teaching in an overly simplified way, the technique applied is encouraging independent thought by active participation. Once again, tutors and students are participating as if equals and not fragmented by their status or level of knowledge but unified by the fact that they are learning from each other. Lastly, considering the fact that every generation has its own way, this dialectical method is shared by tutors and students of all ages and of all various empirical awareness thus ensuring again a smoother dissemination of knowledge.

*"Travailleur : tu as 25 ans mais ton syndicat est de l'autre siècle."
(Worker: You are 25, but your union is from another century.)*³

Influential slogan of the May 1968 protests in France



Fig. 5

Critical thinking tutorials– AA Dlab London.

Building Facilities

*"The building of an architecture school beyond the teaching staff, curriculum, etc is what makes an architecture school be what it is."*⁴

Farshid Moussavi

This is perhaps one of the most fundamental and important statements that depicts the peculiarity, the distinct trait which a school of architecture should be characterized

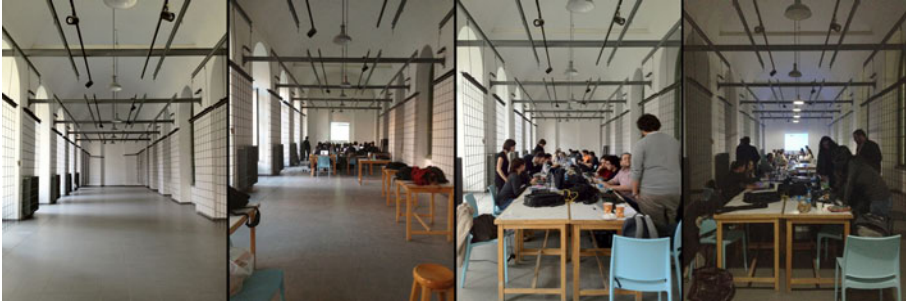


Fig. 6
Educational space transformations – AA Istanbul.

by and which the educational system should always strive to apply to its institutions. As a basic belief that the built environment is an indirect but nevertheless crucial factor that influences ones' perception, thinking and behaviour, the AA Visiting Schools in Athens, Istanbul and London adapt their teaching techniques in order to ensure that the location is contributing positively to the students' experience.

The common fact that social and technological conditions affect the way in which we experience our built environment is to be considered as an additional layer and opportunity for ameliorating our apprehension of different building typologies. In some examples of an institution's building design, like the one in the School of Architecture in Umea, Sweden, the designers predefined the layout and the finishes of the school in their effort to anticipate the students' way of work. The idea was that by making the school look and feel like a corporate institution, the generations of students will already be prepared to take on a position at big commercial architectural firms.

In contrast to this approach, the three AA Visiting Schools have a less predefined concept of what a classroom should be like and focus more on having a flexible space capable of accommodating different activities throughout their duration. Specifically, every School is in a position to alter its layout not just in form, but also in size; different educational activities such as lectures, tutorials or presentations call for different layout adjustments and in the same manner difference in numbers means difference in size. These alterations take place immediately and they would only happen when the need for them is discovered. In this manner, the key element of understanding the necessities of each School at the moment of their occurrence and the ability to conform accordingly is what enables a perfectly consistent, seamless and scale-less learning experience.

At a larger scale, these AA Visiting Schools are not only rethinking the way in which they operate within the institution's premises but they are also taking into account their distinct geographical locations. The AA Athens School is setup to run consecutively with the AA Visiting School in Istanbul as they have connected agendas and are geographically closely located. More specifically, AA Istanbul Visiting School re-discovers verticality through novel computational techniques and physical prototypes

by creating a connection with AA Athens Visiting School. The structure operates as an interactive platform that is initiated between the two schools where related generative methods are investigated towards an integrated design system which oscillates between verticality and horizontality. AA Athens Visiting School puts interactive design to the test by building novel experience prototypes upon horizontal planes. The final produced archetypes are then re-examined to the AA Istanbul Visiting School in order to create an actual connection between two distant locations. End-results of one school will become design counter-arguments for the other and vice versa which what allows for an orderly and logical transition from one place to the other.

Similarly, the AA Visiting School in London, also known as AA DLab, is taking advantage of two different locations in UK. The participants of AA DLab get the chance to experience two different places which share different characteristics. In this case, the concept combines two aspects; the early guidance and the later practice. At first, learning is taking place at the premises of the Architectural Association in London where it is conducted through observation and imitation, verbal exchange and audio and video recordings. While informed and prepared via tutorials, the participants are then encouraged to have their first situated knowledge by engaging on special sessions which embody manufacturing techniques. In this way, the students are able to get a hands-on experience of the actual agenda of this AA Visiting School which focuses on the use of diverse range of digital fabrication systems like CNC printers/routers, 3D Printers and more. This method of generating knowledge from experience or by trial and error is being complete when AA DLab is relocated outside London, in Hooke Park. In the area of Hooke Park, the participants are asked to recreate their design proposals while considering the fact of having them fabricated as large-scale models. Thus, the learning experience comes into full circle from initial tutorials, presentations and trial modelling all the way to digitally fabricating large scaled prototypes providing this way a coherent model for learning architectural design and fabrication.

Professional Alertness

"All institutions should limit their lives and plan for their own extinction."⁵

Cedric Price

Today, Universities across the world tend to alienate students from a competent, masterly preparation towards their future professional employment; the gap between becoming a graduate student and an adept, ready-to-be employed architect is becoming ever wider. By exploring different design and make methodologies which then creates a way to question architecture, it is possible to enrich and realign the discipline's definition and application and bridge the segregation from academia to profession.

Under this light, the tutoring teams of the three Visiting Schools are comprised by people who are already experienced and still are working in small and big offices. By combining their trained skills with their theoretical knowledge on architecture and specifically on the topic in-hand they offer a unique guidance and schooling for the students. In addition, a set of lectures and special events are carried out by external



Fig. 7
Professional correlations – AA Athens.

invited professionals. The dissemination of their practical experience constitutes an invaluable means of advancement to aid the students accelerate their understanding in matters of new design anatomies and begin developing a more practical side to their theoretical background.

As part of the Architectural Association's development vision, the Visiting Schools in Istanbul, Athens and London are open not only to architectural students but also accept colleagues who are already practicing in the field of architecture. Consequently and concurrently with the fact that these are participants from different parts of the globe, the act of passing on knowledge gains an auxiliary, indirect, but intended way to reach the ever more interested participants. Having all the above into consideration, one begins to realise how the Architectural Association Visiting Schools in London, Istanbul and Athens confront the current situation of the architectural education and provide solutions to a problematic that was also observed by Peter Buchanan who once said:

*"Detached from the ferment of epochal change, the groves of academe are failing to engage with current critical realities. Education for architects must be radically reconsidered, through a new, more fully human paradigm that engages with society and culture."*⁶

Design Case Studies

*"The structure of the city and the house of tomorrow will be fleeting almost something fluttering and whenever possible, immaterial."*⁷

Zenetos

As a main goal, the AA DLAB and AI (Athens-Istanbul) workshops of the Architectural Association constantly re-examine fundamental architectural elements and redefine their characteristics by challenging their existing and entrenched in time definitions. These three Visiting Schools also investigate the possibilities of novel digital tools that allow for an architecture where the relationship between the design and the construction is characterized by an orderly, logical, and aesthetically consistent direction. This challenge is approached by the concept of computation, digital fabrication and interactivity. The AA Athens, Istanbul and London Visiting School introduce a combination of a theoretical and practical approach to the challenges that architecture is opposed to by today's cultural and social facts. In a period of 15 days, participants with different



Fig. 8

Multi-layered networking performance – AA Athens.

levels of experience –from 2nds year students to PhD candidates and full-time professionals- experienced a highly-focused unit-based educational system with shared agendas which promotes collaborative design, research and performance.

During these AA Visiting Schools, both the tutoring team and the design teams faced the challenge of short-timed project proposal using computational tools as well as with the use of digital fabrication machines in a fully contextualised architectural problematic. In these schools, the aim to achieve interesting design solutions through the use of the latest technological developments is accomplished successfully by actually making use of all possibly accessible technological equipment today. The final results are presented not as merely attractive images on the screen but as digital prototypes filled with elaborate information that render the digital fabrication possible. Thanks to the development of scripting languages targeted for design and to the advances made towards having in-house digital fabricating machines of different sizes, the process of conceiving a design to producing a physical model has ever been more coherent. Just by simply making the proper correlations between the information on screen to the ones that drive the fabrication process, the act of producing architectural drawings becomes consistent and rapidly more empirical. In many examples seen in these AA Visiting Schools, one clearly witnesses the benefit of quickly testing out designs and examining them through their fabrication. The participants, who engage in this active learning technique, are able to acquire a more direct and highly situated knowledge of what it is they are involved in. The theoretical proposals of the past are now achievable and realisable through the power of computation and digital fabrication. By directly controlling the drawings through customized computer design programmes, the workflow linking drafting and construction evolves and becomes more intertwined. The learning experience is as strong to the participants as it is to the tutors. Being productive, credible and capable to complete a project is a responsibility shared by students and tutors. Furthermore, the collaboration among different educational institutions provides the tutors from Athens, Istanbul and London with the benefit to expand their teaching abilities and become more knowledgeable in working with international targeted groups. In addition, the actual travel from one location to another contributes to the entire experience. Especially in the case of the students it becomes very effective as a training practice as they become more aware of the design potentials of AI and DLab fundamental concepts and methods while observing the systematic approach applied in these different places of different worlds.

The segregation between the architect and the end-result diminishes even more with the progression of the user interface as an architectural tool. With the ability of having a more sophisticated control in architecture in both the design and fabrication method process the AA Visiting Schools are directed towards architectural themes that are dynamic and that are characterized by action. The concept of having a structure that is related to motion and real-time reaction to external stimuli is no longer an idea of the past but can be realized by means already being used in everyday life allowing for the architect to enhance his/her understanding of the project under discussion. Through several projects indeed, it became evident that there is a clear connection between interactive versus non-interactive design and active versus passive apprehension of an object, as well as the active and passive participation in events or activities, leading to the accumulation of personal knowledge of architecture.

Conclusion

*"It is neither necessary nor useful to invent a new architecture every Monday morning."*⁸
Ludwig Mies van der Rohe

Architecture has a tendency to be driven by society's concurrent movements and inclinations and if not unchecked, then Architecture will most likely tend to be also entrapped and languish within society's same inclinations. Evidently, every radical movement in architecture began by questioning the well-established system of its' time and eventually concluded its' cycle of revolution by becoming itself yet another conventional, academic impression. Although, it is not necessary for oneself to re-invent its' own identity at every moment of every day, it is still very crucial that one does not become too comfortable by its own reassurances.



Fig. 9
Interactive empirical prototype – AA Dlab Hooke Park.

Each student, professional or institutional body acclaiming creativity must first acknowledge the need of constant adaptation to the socio-economic fluctuations and seek self-rediscovery through questioning and re-examination of one's own fundamental views. The key to revitalize the Design Discipline lies in the re-linking of all its' stages –from early guidance to later practice. In a society of corporate ideology and global marketing, Architecture should strive to re-invent its role by engaging a more human paradigm on all levels/scales of the practice. This paradigm should affect the person from the beginning of his/her training and continue to shape their ideologies during their professional career. This is a principle which the AA Visiting Schools in Athens, Istanbul and London strive to respect by constantly promoting a type of inquisitiveness for rediscovery throughout the different scales and layers of architectural education.

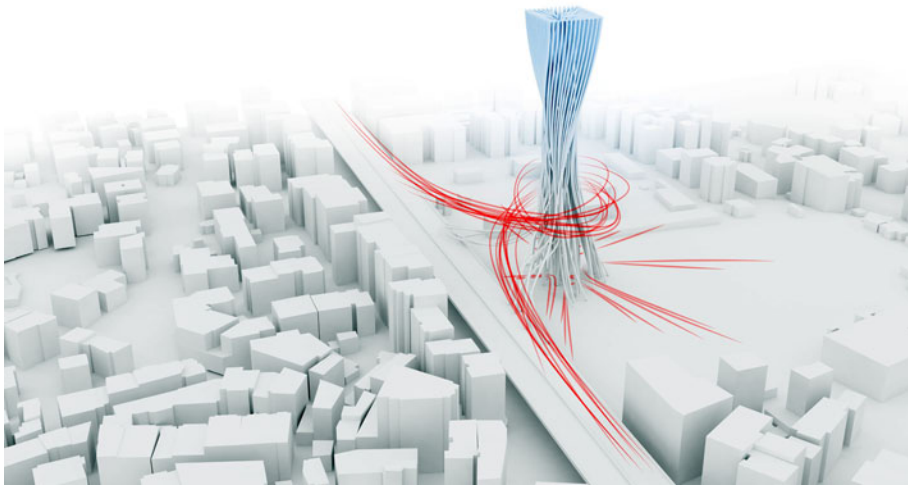


Fig. 10
Interwined tower design concept – AA Istanbul.

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**Architecture in the Field
of Ambient Intelligence:
Towards a “Digital” Layer
in Buildings**

Introduction

Since the 1990s a growing interest in the so-called adaptive architecture, seems to be shared among architecture schools, experimental research groups and practices. This involves physical transformable structures able, in theory, to adapt to constantly changing needs and environmental conditions, through the use of kinetic mechanisms and embedded computation (wireless networks, micro-processors and sensor-actuator effectors).¹ In particular, transformable structures consist of moveable interconnected parts which can rearrange their relative positions, according to demand, either manually or through control systems. The result is a significant overall mechanical change of their physical configuration, which is determined by the set relations of their internal components and their inbuilt kinetic mechanisms. The latter may range from mechanisms of deployment, folding and extension, to rolling, sliding and nesting techniques, and from scissor-type mechanisms and inflatables, to tensile and transergetic systems. However, adaptation in such structures is limited by design and a finite number of predetermined physical rules. Structures such as those discussed in William Zuk and Roger Clark's book *Kinetic Architecture* (1970),² as well as those recent computationally-driven structures by the Hyperbody Research Group at TUDelft (Fig.1), seem to be "closed" systems, i.e. their adaptability is limited by the range of the transformational constraints of their structure and components. The determinable degree of freedom of movement that they are able to produce means that the range of possible functional changes that may occur is predictable; this is because the form



Fig. 1
Transformable structure by Hyperbody (TUDelft).

can only “respond to a range of functional changes possible within the initial envelop limitations”.³ Therefore, flexibility, although dependent on the multiple transformational states of the structure, is confined within a narrow range of alternatives, predefined by design.

Yet the paradigm for a flexible adaptive technology-driven architecture can be traced back to the discourse and practices of the cybernetics-inspired avant-garde architects of the 1960s and, in particular, Cedric Price and Archigram. Putting aside deterministic preoccupations with form and function as well as mechanistic interpretations of flexibility,⁴ they sought an open-ended user-driven indeterminate architecture able to adapt to uncertainty. They postulated the concepts of ‘indeterminacy’ and ‘open-endedness’ in architecture, and thought that its inhabitants would have an active and participatory role in the determination of its configuration and functions.⁵ As we have argued elsewhere,⁶ the Archigram project, as well as Cedric Price’s *Fun Palace* and Constant’s *New Babylon*, despite their different conceptual, material and visual aspects, constituted an alternative paradigm of flexibility, one which Adrian Forty considers to be not a characteristic of buildings but of *use*.⁷ In such a case, flexibility is not determined by design or technical means but by the participatory and constructive engagement of those who use space, namely ‘users’.⁸

In this paper we will attempt to argue that a possible shift in the conceptualization of adaptive architecture can be traced within the field of computer science called *Ambient Intelligence* and the applications of *end-user driven Intelligent Environments and Tangible Computing*. These systems can supply both concepts and techniques for the implementation of open-ended adaptive architecture, with indeterminate, and user-defined multiple functionalities. As we will show, in this case, the question whether architecture as a discipline faces a possible epistemological shift, is inevitably placed.

Ambient intelligence

Intelligent environments

Ambient intelligence (Aml) is a vision of the field of computer science aiming by definition at the creation of spaces, the so-called *Intelligent Environments*, able to respond to the presence and activities of people in an adaptive and proactive way by supporting and enhancing their life through smart devices. Although automatic buildings have been around since the 1950s and 1960s,¹⁰ intelligent environments are different because they have developed complex and adaptive ways to enhance domestic habitation through the use of ubiquitous computing (neural nets and fuzzy logic supported by networks of intelligent agent-based systems) and user-friendly interfaces.¹¹ Without attempting to discuss the perpetual meaning of *intelligence* as analyzed in the fields of Artificial Intelligence and Cognitive Science, it is sufficient to say that, in the context of Aml, it refers to autonomously functioning systems able to provide automated services, assessing situations and human needs in order to optimize control and performance in architectural space. Such systems use environmental information -acquired through activity recognition / detection- as feedback to obtain knowledge and experience, through learning, memory and proactive anticipation mechanisms, in order to adapt to personalized needs as well as changes of user habits.¹² Such environ-

ments, a.k.a. autonomous intelligent environments, would include the iDorm, an experimental student apartment developed at Essex University, the PlaceLab, developed by House_n research program at MIT, the Adaptive Home, and the MavHome.

Intelligent environments model the activities and behavior of users,¹³ in order to produce rules to determine and optimize their performance. They are thus able to adapt to new behaviors and respond accordingly. However, although intelligent environments can adapt to changes of the habits and activities of their occupants, the system's responses, its performing functions, are predetermined. In effect, these functions are limited by the range of human or environmental activities that the system is programmed to be able to recognize, supported by the intelligent agents' capacities and the knowledge it obtains in time through learning. Furthermore, the high level of system autonomy in mainstream intelligent environments does not permit any modification of the system's rules. Adaptation is limited by a finite number of predetermined rules because most applications of intelligent environments are only able to respond to a prescribed range of human activities and needs that the system is able to recognize, while any possibility for appropriation of their functions is restricted by the autonomy of the system.

On the other hand, a different set of Ambient Intelligence applications, the so-called *end-user driven intelligent environments*, constitutes an alternative direction to mainstream intelligent environments because their function is not dependent on the pre-programmed rules of the system. This approach can be traced in a conceptual path alternative to traditional HCI research, within which system designers are no longer in control of interaction; instead, this path focuses on techniques to allow user customization of the artifacts, i.e. to modify and deconstruct their interface, relocating their constituting elements.¹⁴ *Tangible computing* applications, discussed below, provide a path towards the implementation of such environments.

Tangible Computing and End-user Driven IEs

Tangible computing is a term used by Paul Dourish in the context of his *embodied interaction* theory which examines how meaning is produced, managed and perceived through direct interaction with objects.¹⁵ Tangible computing in this context refers to the exploration of how to move computers out of sight and provide people with a more direct –tangible– experience of interaction.¹⁶ Tangible computing systems, which are part of the wider field of intelligent environments applications, involve everyday environments, objects or devices enhanced with computational power, so that they will be able to become active agents, reacting to their environment and the activities of people, while knowing their location and their neighboring context. However, unlike traditional computational devices, such as mice, computer interfaces, keyboards etc, these systems interact with users through the affordances of everyday objects in 3-dimensional physical space.¹⁷ In order to turn physical objects into tangible computing objects they must be augmented with hardware and software components which incorporate and determine their functionality.¹⁸ Digital information is thus embedded in physical form while manifesting itself through physical changes in the domestic environment: for instance, lighting patterns, sound signals or movement

of furniture and architectural elements. As far as hardware is concerned, tangible computing artifacts must have batteries, a processor, sensors and a wireless communication unit. This augmentation provides artifacts with a digital self, that is, a representation in the digital space, which can be perceived by other artifacts. On the level of software, hardware drivers are necessary to manage information exchange between the operating system and the external resources (sensors, actuators, screen etc). A networking subsystem is also needed for the exchange of messages between artifacts, as well as an operating system able to manage the use of resources and to translate service requests into commands to resources and vice versa. Also a middleware is needed to provide abstractions that enable an artifact to be part of a distributed system.

In tangible computing systems, there is no single point of interaction, a single device to interact, as in traditional human computer interaction interfaces. The same activity can be distributed and shared between multiple devices or, more specifically, it can be achieved through the coordinated use of these artifacts.¹⁹ At the same time, interaction does not take place in a successive manner of information exchange, but in parallel, as there is no way to tell the next action of the users, because there are many ways in which they can perform their actions. According to Kameas et al., the points (properties and capacities) in which tangible computing artifacts differ from traditional objects are:

- The artifacts possess information about their functionality, instructions for the execution of functions, and messages that can be sent to or received from other artifacts. Artifacts can process this information which appears in the digital space as data on what services the artifact can offer or request from other artifacts.
- Artifacts can interact with their environment, understand the context of their use through sensors or by communicating with other artifacts, and respond to these stimuli using actuators.
- They also have the capacity for collaboration, i.e. they can exchange messages with other artifacts -from simple to complex data, such as programs and databases- through wireless communication.
- They can be combined with other objects, that is, they can be used as virtual building blocks of larger and more complicated systems. This can be achieved through their embedded communication unit and the capacity to publish their services to other objects.
- They also have the capacity to change or disconnect the digital services that they offer.²⁰

Following this path, end-user driven intelligent environments such as *PiP* (pervasive interactive programming) and *e-Gadgets*, enable users to program and appropriate their environment by “building” their own virtual appliances according to their special desires. These systems provide the tools to construct personal Aml applications in domestic environments that are adaptable to users’ indeterminate needs and changing circumstances. They can empower users to appropriate the system and its operational rules in a creative and even improvisational way through user friendly interfaces. In the case of *PiP*, users can deconstruct the system, by choosing and combining different device functions thus forming “virtual pseudo-devices” (Meta-Appliances – Ap-

plications).²¹ In the e-Gadgets case (Fig. 2), users would choose the combinations connecting plugs of smart components graphically, namely flexible blocks with no predetermined capacities and an “open” function mechanism (eGadgets), creating synapses and rules of the “if...then” type.²²

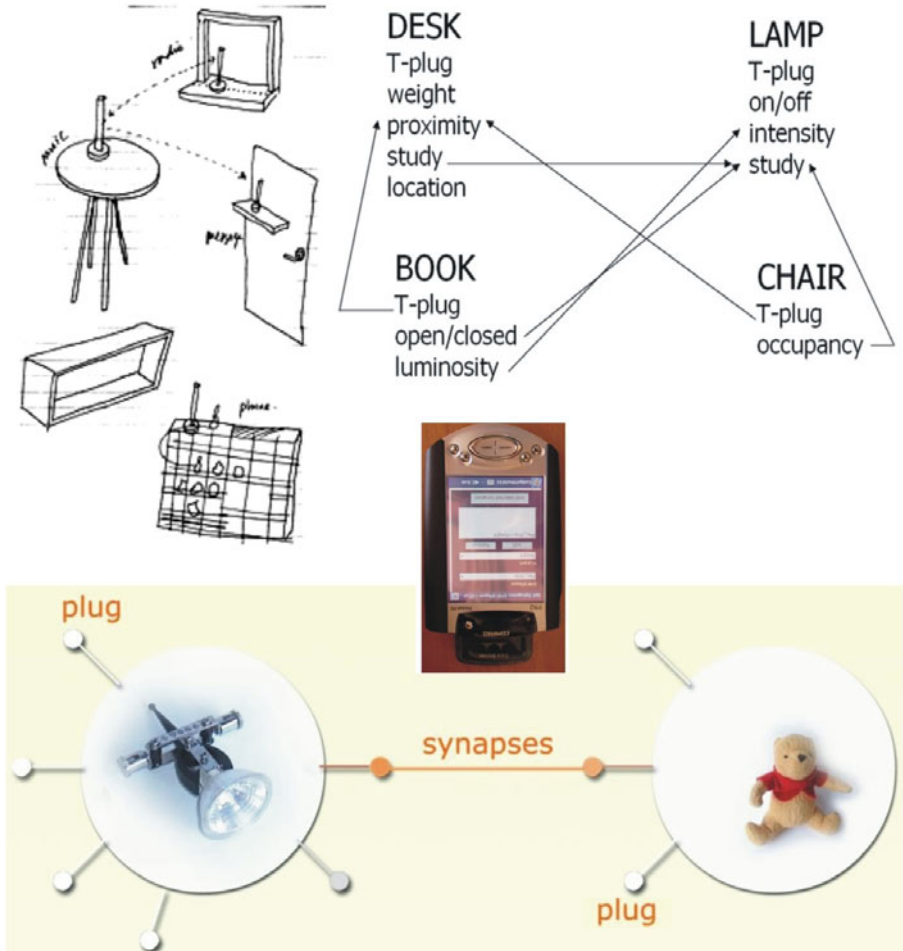


Fig. 2
e-Gadgets.

The functional capacities of end-user driven intelligent environments derive from the interaction and cooperation of heterogeneous components, artifacts and people, for the optimization of the behavior of the whole. Therefore, the actions of the users in such environments are not always successful in terms of their functional outcome, because this outcome depends on the dialectical relationship, the ‘conversational’ process, between user and environment (the technological artifacts that constitute it). Zaharakis and Kameas (2007) discussing the potential of end-user driven environments

such as *e-Gadgets* have argued for a conceptualization based on biological paradigms thinking of them as symbiotic ecologies of heterogeneous actors, where intelligence is collective and an emergent outcome of their interactions.²³ Such environments are “ecologies” of interacting artifacts, processes, human users, infrastructure and software, demonstrating open-ended, indeterminate and multiple functionalities. The subject -the user- is part of that environment and his/her embodied actions within it are essential for the way he/she relates to it.

Architecture and End-user driven IEs

End-user driven Aml applications may present a possible future for the conceptualization and design of architecture that is able to respond to the indeterminacy of human desires and unanticipated circumstances, as opposed to the predetermined paradigm of adaptation. To explore this possibility we need to cease thinking of adaptive architecture as a functionally predetermined kinetic system, bearing analogies with mechanical machines, but rather attempt to conceptualize it as a *virtual machine*, a *machinic assemblage* of underdetermined functions, emergent behaviors and “open potential”;²⁴ an “ecology” of interacting techno-social entities -artifacts, human users, and software- demonstrating open, indeterminate, multiple and user-customized functionalities.

The “digital layer”

To engage Aml applications in the conceptualization and implementation of adaptive architecture we will borrow Bernard Leupen’s concept of “frame” in his historical analysis of the relation between the permanent and the changeable part in buildings. In his book *Frame and Generic Space*, Leupen reviews a large number of mainly 20th century buildings analyzing their potential for flexibility and changeability through the exploration of the permanent rather than the temporary layer of their organization. This layer he calls “frame”. To do this, methodologically he defines a system of 5 layers composing every building –structure, skin, scenery, services and access- which can acquire the role of the “frame” (the permanent layer) either alone or in combination with others.²⁵ Thus he manages to propose an analysis of buildings by deconstructing them into these 5 layers. Following his analysis, in this paper, we can propose another layer in the order of the above that theoretically would enable architecture’s adaptive, “open” and indeterminate capacities. This layer we will call “digital”. The “digital” layer will be an assemblage of “intelligent” devices and software –i.e. agents with input, output and communication plugs- able to respond to the changeable needs and desires of occupants, through the management of information and energy supply within the domestic environment. Using the techniques and “philosophy” of end-user driven intelligent environments, the components of this “digital” layer will be functionally “open” mechanisms able to be programmed and reprogrammed by users, allowing customization and user-driven system behaviors.

In this case, the “digital layer” constitutes the changeable part within the framework of Leupen’s analysis, while the building, consisting of all 5 of Leupen’s layers, constitutes the “frame”, the permanent part. Yet this changeability does not involve material, that

is, physical transformation of architecture. It involves changes in the personal sense of comfort, the ambience and the sensory perception of the domestic environment, achieved by information and energy management devices driven by the occupants of the environment.

Questioning the disciplinary limits of Architecture

Although this attempt to conciliate architecture with ambient intelligence applications in order to propose a more adaptive architectural environment is a theoretical one, the field is open for exploration by architects and researchers. In all conferences on intelligent environments worldwide (such as IE, Ubicomp etc) architect presenters are rare, whereas papers rarely discuss issues relevant to spatial or architectural parameters. Discussions and debates circle around the concerns of computer scientists and engineers rather than architects. Is this because these two fields (architecture and ambient intelligence) are irreconcilable? Or is it because we, as architects, have yet to develop a more open definition of architecture, extending our role and our form of practice? Should the profession of architecture engage a form of practice that no longer places the act of making buildings as the central and defining role of the architect? Are we then witnessing a possible epistemological shift of the very identity of architecture, that is, a shift from the “hardware” of space -the built environment- to the immaterial architecture of “software” infrastructures and network configurations?

To give a quick response to these questions we will have to look back again, to the visions of those cybernetics-inspired avant-garde practitioners and theoreticians of the 1960s, such as Archigram, Price and Banham, who proposed a similar shift. Stanley Mathews has argued that Cedric Price’s Fun Palace, one of the first buildings to make use of cybernetics and systems technologies for continual adaptability of architecture to transient social conditions, “challenged the very definition of architecture, for it was not really a ‘building’ at all, but rather a matrix that enclosed an interactive machine.”²⁶ In his essay “A Home is not a House”, Reyner Banham consistently operates critically upon the conventions and the norms of the discipline of architecture.²⁷ The projects *Standard-of-living Package* and *Anatomy of a Dwelling* (Fig. 3), illustrated by the artist François Dallegret in the essay to depict archetypical dwelling environments, seem to suggest a shift in architectural priorities as the house and its materiality, its form and envelope, are quite literally nearing invisibility, whereas architecture’s disciplinary limits are questioned. Anticipating his later book *The Architecture of the Well-Tempered Environment*, where he proposed an alternative architectural history seen through the lens of environmental control rather than through typology and form, Banham challenges the very identity of architecture shifting its definition from the monumental, the permanent and the enclosed to the environmentally sensitive system, the light, and the temporary.

Such a shift, which is echoed in Marshall McLuhan’s idea of architecture as an organic extension of the human body and regulator of environmental perception,²⁸ seems to be shared with the Archigram visionary project. At some point in their drawn work, Archigram favored a lightweight and personalized architecture, as depicted in projects such as *Suitaloon* and *Inflatable Suit-Home* (1968), as well as the idea of archi-

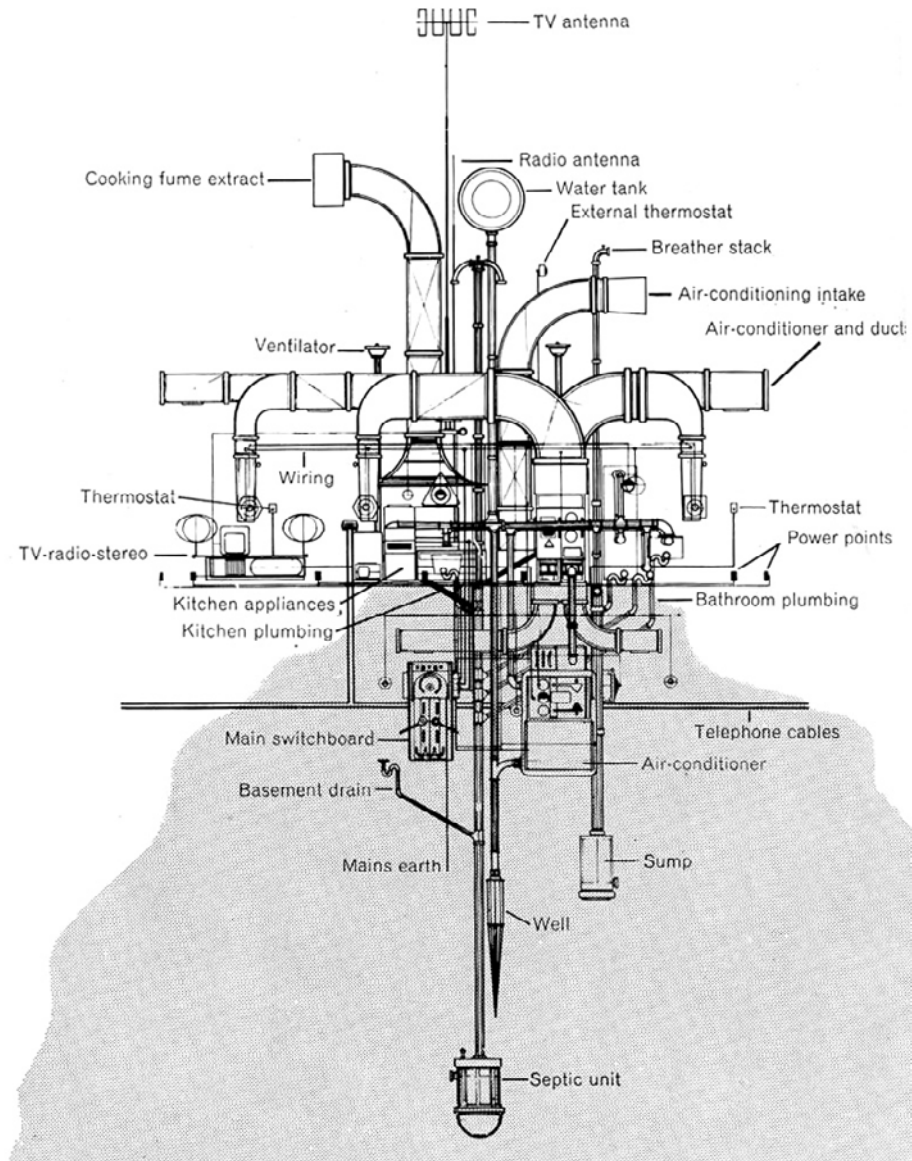


Fig. 3
 Dallegret F, *Anatomy of a Dwelling*, 1965.

ecture as a cybernetic information feedback system, an interface between the human body and the environment, able to respond directly to personal desire.²⁹ In a number of visionary drawings, such as *Holographic Scene Setter* (1969), and *Room of 1000 Delights* (1970), architecture, no more the design of hardware, would dissolved into the "software", i.e. programs to enable diverse situations in a given space.³⁰ Architecture

that our proposal problematizes the very disciplinary limits of architecture. Although our proposal is theoretical, that is, it does not discuss at length any actual example or any evolved research, we believe that the fact that similar questions can be traced back to the 1960s discourse and practice enhances the importance of our investigation and concern further. But rather than shifting architecture's definition towards the immaterial and the transient, in the manner attempted by Archigram or Banham, we would rather extend it to include not only the permanent part of buildings (the "frame"), but also the hardware and software configurations and artifacts, i.e. the "digital layer" of adaptive architectural spaces.

Notes

- 1 See Fox, M., Beyond Kinetic. [online] Kinetic Design Group. Available at: <<http://kdg.mit.edu/Pdf/Beyond.pdf>> [Accessed 30 January 2006]; Fox, M. and Yeh, B., Intelligent Kinetic Systems. [online] Kinetic Design Group. Available at: <<http://kdg.mit.edu/Projects/pap01.html>> [Accessed 30 January 2006]; Fox, M., "Catching up with the Past: A Small Contribution to a Long History of Interactive Environments" *Footprint: Delft School of Design Journal* (Spring Issue: Digitally Driven Architecture) 6, 2010, pp. 5-18.
- 2 Although kinetic architectural elements and structures have existed since antiquity and in different cultures they were more widely recognized and developed throughout the second half of the 20th century due to the rapid changes in the western way of life. In particular, from the Second World War till recently, kinetic structures such as those transformable lightweight and deployable or portable environments, built by architects and firms such as Buckminster Fuller, Hoberman associates and FTL Happold, to name a few, have sought to resolve economical, practical or ecological problems of the construction industry, and respond to issues of survival and nomadic dwelling. For discussion, categories and overview see Kronenburg, R., *Portable Architecture*, Oxford: The Architectural Press, 1996; Oungrinis, K., *Structural Morphology and Mobile Structures in Transformable Spaces* (in greek), Ph.D. Aristotelian University of Thessaloniki, 2009.
- 3 Zuk, W. and Clark, R.H., *Kinetic Architecture*, New York: Nostrand Reinhold, 1970, p. 98.
- 4 Flexibility was an emerging idea in architectural discourse during the post-war period to deal with the uncertainty and rapid development in the Western world brought forth by the constant social and economic changes. However, as Adrian Forty argues, the application of flexibility in architectural design gave architects the illusion that they can sustain and extend their control on buildings even after the period of their real responsibility, the design stage. See: Forty, A., *Words and Buildings: A Vocabulary of Modern Architecture*, London: Thames & Hudson, 2004, p.143. Thus, flexibility in architecture is by definition limited by design, i.e. it is predetermined.
- 5 Sadler, S., *Archigram: Architecture without Architecture*. Cambridge MA/London: MIT Press, 2005; Hughes, J., The Indeterminate Building, in: *Non-Plan: Essays on Freedom Participation and Change in Modern Architecture and Urbanism*, Hughes J. and Sadler S. (eds.), Oxford: Architectural Press, 2000, pp. 90-103
- 6 see Yiannoudes, S., *Adaptive Architecture: Capacities and Design Factors of Transformable and "Intelligent" spaces* (in greek). Athens: ION Press, 2012.
- 7 Forty, op. cit.
- 8 The term "user" in this context would not only mean the person that has the potential to use space but also to appropriate it, inhabit it, determine its manner of use at will, creatively re-interpret it or even abuse it (Forty, op. cit., pp. 312-315).

- 9 see Streitz, N., "Designing Interaction for Smart Environments: Ambient Intelligence and the Disappearing Computer", in: *The Second International Conference on Intelligent Environments*, 1, Athens: On Demand, 2006; ISTAG, *Ambient Intelligence: from Vision to Reality*. [online] European Commission CORDIS. Available at: <ftp://ftp.cordis.europa.eu/pub/ist/docs/istag-ist2003_consolidated_report.pdf> [Accessed 8 March 2005].
- 10 For instance the *All Electric House* built by General Electric Company in Kansas in 1953 involved remote controlled assistive services such as setting on /off the lights, watering the garden or coffee making.
- 11 Ahola, J., *Ambient Intelligence*. [online] ERCIM News. Available at: <http://www.ercim.org/publication/Ercim_News/enw47/intro.html> [Accessed 17 July 2007].
- 12 Cook, D. and Das, S., "How Smart are our Environments? An updated look at the state of the art", *Pervasive and Mobile Computing*, 3(3), 2007, pp. 53-73.
- 13 Of course there are drawbacks to this capacity including difficulties in recognizing simultaneous activities or activities performed by more than one user.
- 14 Dourish, P., *Where the Action is: The Foundations of Embodied Interaction*. London/Cambridge MA: MIT Press, 2001, p. 16.
- 15 Ibid., p. 126.
- 16 Ibid.
- 17 Ibid.
- 18 Kameas, A., Mavrommati, I., & Markopoulos, P., "Computing in Tangible: Using Artifacts as Components of Ambient Intelligence Environments", in: *Ambient Intelligence: The evolution of Technology, Communication and Cognition*, Riva, G., Vatalaro, F., Davide, F., & Alcaniz, M., (eds.), Amsterdam/Oxford/Fairfax: IOS Press, 2004, pp. 124-125.
- 19 Dourish, op. cit., pp. 50-51.
- 20 Kameas et al., op. cit., pp. 122-123.
- 21 Chin, J., Callaghan, V. and Clarke, G., "A Programming-by-Example Approach to Customising Digital Homes", *The Fourth International Conference on Intelligent Environments*, [CD] Seattle, USA, 21-22 July 2008. Instn Engg & Tech.
- 22 Kameas et al., op. cit.; e-Gadgets, *e-Gadgets*. [online] Available at: <<http://www.extrovert-gadgets.net/intro>> [Accessed 13 February 2009].
- 23 This discussion can be informed by post-cognitivist theories and the social studies of technology, such as Actor Network Theory, distributed cognition theory, activity theory and embodied cognition/interaction theories, which, despite their differences, seem to conceive the word as a hybrid techno-social environment consisting of heterogeneous associations, liaisons and synergies between humans and non-humans (tools/machines/artifacts/technologies). For a thorough attempt to contextualize intelligent environments and adaptive architecture within these theories see Yiannoudes, op. cit.
- 24 For a more in-depth discussion of these concepts in relation to adaptive architecture see my paper: Yiannoudes, S., "From Machines to Machinic Assemblages: a conceptual distinction between two kinds of Adaptive Computationally-Driven Architecture", *EAAE Transaction on Architectural Education No.55: Rethinking the Human in Technology-Driven Architecture*, 2011, pp. 149-162 [Technical Univ. of Crete, Dept of Architecture, Chania, 30-31 August 2011]
- 25 Leupen, B., *Frame and Generic Space*, Rotterdam: 010 Publishers, 2006.
- 26 Mathews, S., *From Agit-Prop to Free Space: The Architecture of Cedric Price*, London: Black Dog Publishing, 2007, p. 13.
- 27 Banham, R., "A Home Is not a House," *Art in America*, 2, 1965, p. 75.

- 28 McLuhan, M., *Understanding Media: the Extensions of Man* (Critical Edition), Corte Madera, CA: Gingko Press, 2003 [1964].
- 29 For instance, Peter Cook's drawing *Metamorphosis: Sequence of Domestic Change, part of Control and Choice Dwelling* project [Fig. 4], depicts a prefabricated living room gradually dissolving into an environment where walls become televisual membranes, and inhabitants' desires are detected by sensor cells. See Sadler, op. cit.; Cook, P., (ed.), *Archigram*, New York: Princeton Architectural Press, 1999.
- 30 Steiner, H., *Beyond Archigram: The Structure of Circulation*, London/New York: Routledge, 2009, p. 3.
- 31 Sadler, S., op. cit., p. 132.

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**Project Oriented Database
of Architecture**

Complexity of architectural design process

What is Architecture? Architecture is a broad term which is all about the built environment. Architects provide shelter while integrating the surrounding landscape, open areas, communities, and aesthetics.

Architecture is an exciting field because architects seek to push the boundaries of what we can build. With current technology, we seek to design buildings that not only serve as residences or offices, but are self-sustainable and sit naturally in their environment. Architects impart their creative ideas into structures that fit into the environment and endure for many years, existing harmoniously with nature.

Preserving our environment has come to the forefront of our society's concerns and architects may not be indifferent. Sustainable architecture is a general term that describes an environmentally, energetically and ecologically conscious approach and design techniques in the field of architecture. Sustainable architecture seeks to minimize the negative environmental impact of buildings by enhancing efficiency and moderation in the use of materials, energy, and development space. Energy-saving, sustainable development, natural, recycled materials, renewable resources are all hallmarks of sustainable architecture.

Design in contemporary architecture has become a lot more exploratory in recent years, not only in terms of how design issues are tackled, but also in terms of ecological solutions being implemented.

Contemporary architects are experimenting with more sculptural design ideas. The advancements in digital design tools, 3D software have helped make this possible.

Digital architecture by computer modeling, programming, simulation and imaging allows the creation of both virtual forms and physical structures. Architecture created digitally might not involve the use of actual materials (brick, stone, glass, steel, wood). It relies on "sets of numbers stored in electromagnetic format" used to create representations and simulations that correspond to material performance and to map out built artifacts. Digital architecture does not just represent "idealized space" it also creates places for human interaction that do not resemble physical architectural spaces. Digital architecture allows complex calculations that delimit architects and allow a diverse range of complex forms to be created with great ease using computer algorithms.

According to the new aspects and tools, the architectural design process must become more conscious. By re-thinking the architectural design process as a coordinated set of stages and sub-stages, replacing the traditional experience-related process by a more conscious, rational, and theory based approach choices and solutions for specific design problems, traditionally taken based on experience or individual thinking, can be now taken based on technical awareness and attentive to potential alternatives.

Preventive and remedial measures and decisions should always be evaluated in the context of the whole (holistic approach). In such a designing process the architect can go back to his previous stages and improve his solutions. The designers in their

practice conclude the design process, while they finally choose a specific design form, technique and materials. The content of design stages does not depend on the design tools (e.g. manual or digital), but the connected real and complex database is essential factor (Fig. 1).

Holistic means (from ὅλος holos, a Greek word meaning *all, whole, entire, total*) the idea that all the properties of a given system (physical, biological, chemical, social, economic, mental, linguistic, etc.) cannot be determined or explained by its component parts alone. Instead, the system as a whole determines in an important way how

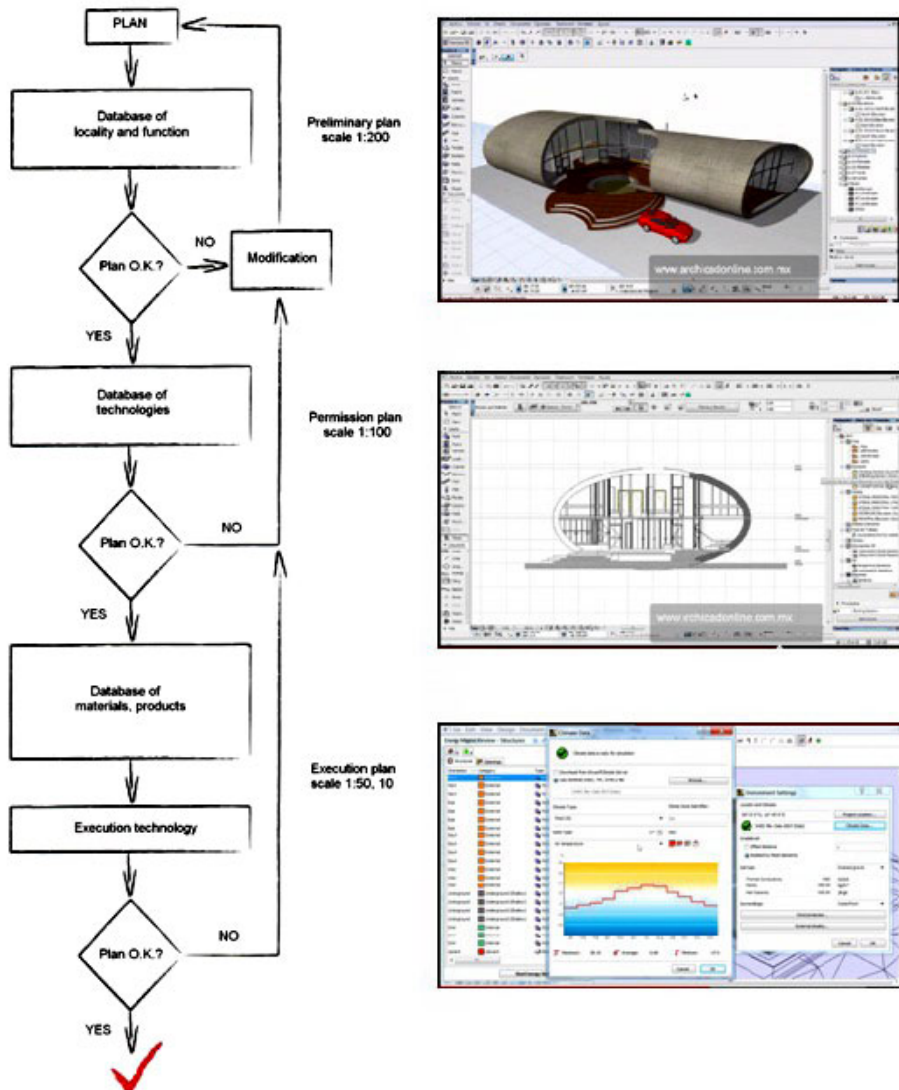


Fig. 1
Architectural design stages with traditional database system.

the parts behave. The general principle of holism was concisely summarized by Aristotle in the *Metaphysics*: "The whole is different from the sum of its parts" (1045a10).

Analysis of effects, requirements and structure, material performances according to the natural, social, ecological parameters at each design stage (performance based design) can be the common ground of the dialogue between the architect and the experts.

It is important to start the performance based holistic activities as early as possible in the course of the project. It is at the stage when the framework is established that it is possible to choose between different structural alternatives. As the project takes shape and becomes more detailed the degrees of freedom and the possibilities of choosing better alternatives are reduced.

The computer aided architectural design opened new era for architects, but without awareness of the basic human and material context of architecture, the digitally generated architectural shapes are only virtual forms, instead of real buildings.

Architectural ideas have found new forms of digital representations, as information reconfigures into digital visualizations, and projects evolve further as digital fabrications. The new genre of "scripted, iterative, and indexical architecture" produces a proliferation of formal outcomes, leaving the designer the role of selection and increasing the possibilities in architectural design.

Holistic design process is very simple and adaptable all over the world together with the local database which allows the fitting of special conditions. Recently this holistic approach sometimes has changed into reductionism. Reductionism in science says that a complex system can be explained by reduction to its fundamental parts.

The question is how to take into consideration the whole complexity of important human attitudes, social, cultural, natural conditions together with integration of scientific results, computerization, challenging of the changed global, natural, economical situation during the architectural design process?

Structural decisions in contemporary architecture

In the designs of great contemporary architects we can recognize the parallelism of formal and structural decisions.

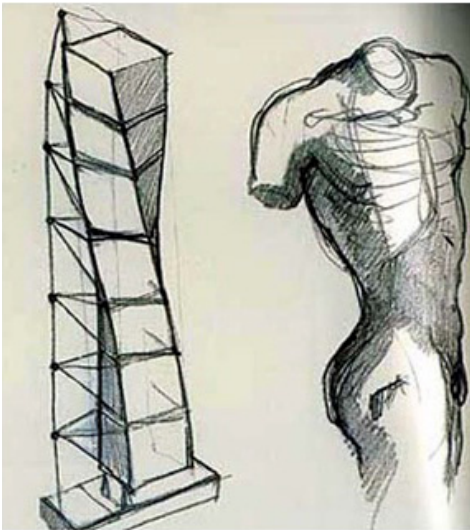
In Santiago Calatrava designs one of the most interesting buildings is the Turning Torso Tower in Malmo, Sweden. The sketches illustrate how he based this idea on the turning of a human torso. The geometry that makes up the Turning Torso Tower is very simple. Each floor is rotated a certain number of degrees to the floor below, giving the building its twisted effect. Once the structural elements are added and the geometry starts to twist, the building starts to develop a sense of complexity.

During the process of designing, it is always important to think about shapes in their most basic element. This will enable designer to figure out how structures fit together.

Calatrava also incorporates sustainable solutions into his designs. Turning Torso Tower has many sustainable features including a system for recycling organic waste into Biogas, which in turn powers the buses of the city of Malmo.

The acclaimed British architect, Sir Norman Foster, is known for the efficiency of his designs. The Swiss Re building and City Hall in London are examples of how he is inspired by abstract shapes.

The geometry in these buildings can be broken down into primitive shapes. Although both have a curved appearance, the Swiss Re building has only one curved piece of glass in its entire structure, which completes the dome at the top of the building. The curved effect is achieved by placing flat quadrilaterals onto a curved structure. The more planes that are used the better the illusions of curvature. Small squares placed along a curve make it smooth; the bigger the quadrilaterals the less the curvature.



<http://www.turningtorso.com/>
Foto: arcspac

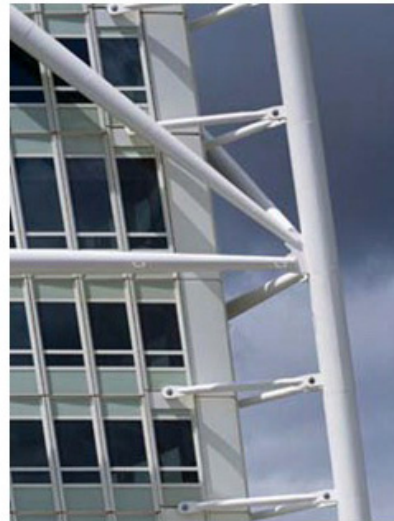
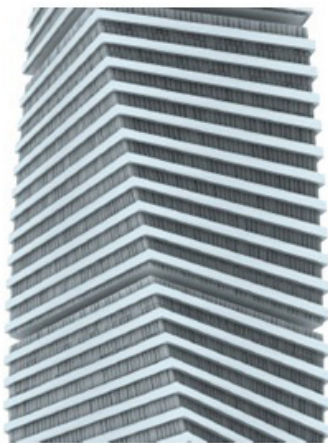


Fig. 2
Santiago Calatrava Turning Torso Tower Malmo.

Foster harnesses a synergy between the building and the environment through the use of natural ventilation and light. This enables people to feel comfortable because they can relate to the outside world.

The Swiss Re building is not only a beautiful design, but also an energy-saving structure. The building has its own microclimate, which has eliminated the use of air-conditioning. Each floor is rotated by degrees from the floor below, enabling the incorporation of a ventilation system. Light and ventilation are huge issues in design and sustainability.

The building could be inspired by natural organic form. It can not be a simple copy of a living creature, but a built version of an idea.



Fig. 3
Sir Norman Foster Swiss Re Building London.

The buildings of great architects prove the importance of structural decisions from the very first step of design process.

The architects have to take into consideration the structural performances based on the evaluation of environmental, functional, social, economical, material data.

Architectural database systems

The efficiency of the design depends on the adequacy of the data applied. Architectural decisions can be correct only if they are based on a comprehensive, real, up to date and appropriate Database. A Database is always unique and local.

The database information can be labeled according to data content, type of data affiliated in a computer program, the targeted group of stakeholders etc.

The Traditional database was an experience based system controlled continuously by builders.

Each stakeholders of project added their knowledge and information into the project. Elements of database were visible and accessible in documentations, maps, catalogues etc (Fig. 4).

Globalization refers to the increasing material wealth, goods, and services through efficiencies catalyzed by international relations, specialization and competition. Almost the same structures and materials are sold all over the world. Globalization also refers to the transnational circulation of ideas, languages, or culture, technical information.

As part of globalization the building elements - materials and components - are arranged on internet through some product oriented building element basis. (Fig. 5). Clients may compare and select from structures or materials as they compile its specification. The elements covered are, external walls, internal walls and partitions, roofs, ground floors, upper floors, floor finishes, windows, insulation and landscaping. These extensive catalogues are continually being updated with specifications covering most common products.

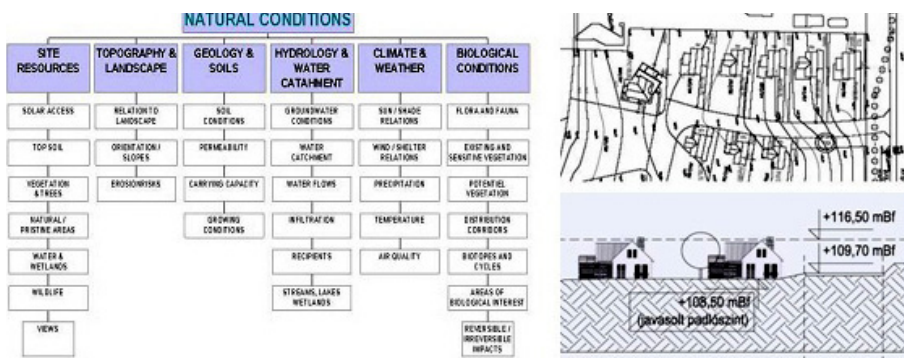


Fig. 4
Traditional architectural database system.

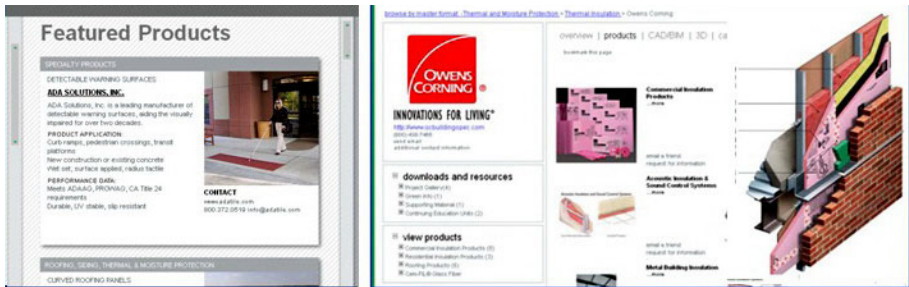


Fig. 5
Product oriented architectural database.

Example for a Computer related database system

Layer	View	Data (What)	Stakeholder
1	Scope/Contextual	List of things and architectural standards ^[3] important to the business	Planner
2	Business Model/Conceptual	Semantic model or Conceptual/Enterprise Data Model	Owner
3	System Model/Logical	Enterprise/ Logical Data Model	Designer
4	Technology Model/Physical	Physical Data Model	Builder
5	Detailed Representations	Actual databases	Subcontractor

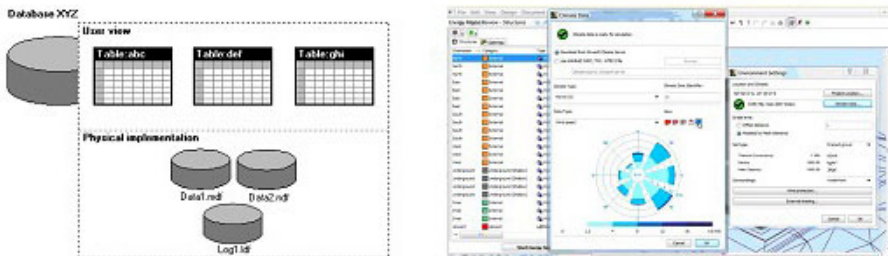


Fig. 6
Computer related architectural database.

Architects have difficulty in choosing the best product from these databases because of the huge amount of elements (one database division – e.g. thermal and moisture protection - could contain more than 10 000 enterprises with their several products!).

The compare the data of different products sometimes is problematic because of the different background (standards, measurement methods, units etc.).

In these databases there is no information about application of structures and materials according to the local climate conditions.

Design process plays a very important role in architecture, not just aesthetically, but technically. As technology evolves and computer software becomes more powerful, it enables architects to explore new possibilities. Architects visualize their designs throughout the process, and explore the shapes that make the structures.

Freed from uncertainty about potential risks, architects and engineers are able to push forward the boundaries of building design creating new forms of expression by taking advantage of the latest materials and construction methods.

Computer Analysis and simulation programs model environmental, technical and economic forces in order to quantify performance and enables us to analyze multiple design options, giving greater choice in the way that environments are designed and ensuring that we are able to offer a range of solutions to meet overall objectives, to be used for a variety of purposes. For example:

- Physical simulations: Testing outside forces and stresses on the building.
- Wind and Turbulence Testing: Testing the turbulence patterns around the building.
- Lighting: Testing lighting of the building to find optimum solutions for natural lighting.

The computer database programs through Database Management Systems (DBMSs) are a ubiquitous and critical component of modern computing. Given these various options, a typical DBMSs needs to be compatible with many different connectivity protocols used by various client drivers Each instance of SQL Server has four system databases (master, model, tempdb, and msdb) and one or more user databases (Fig. 6).

The structure of computer databases are hidden, the architect can use it through the Dialogue boxes, windows. The storage and access of these data depends on the computer program so these are available only for those clients who have the appropriate software. These databases require the high level awareness of applied parameters.

Sometimes this method results with reductionism replacing the holistic approach. Reductionism in science says that a complex system can be explained by *reduction* to its fundamental parts. It could be problematic because of the interaction in between of the environmental impacts and material properties. For example the water and frost together could badly damage the brick.

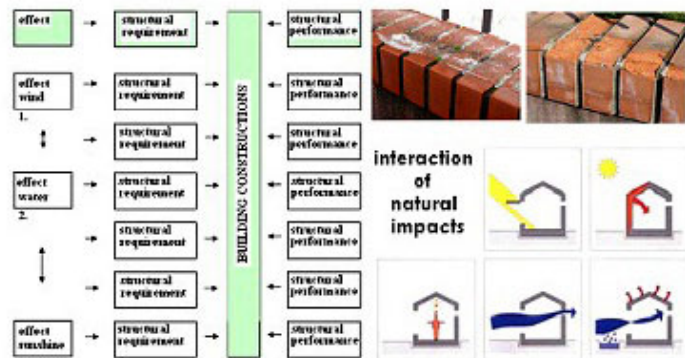


Fig. 7
Complex evaluation method of structural impacts.

Fülöp Zsuzsanna Ph.D. Dissertation 2007.

The complex architectural measurement should always take into consideration the whole building (holistic approach) and each existing requirements evaluated based on the real environmental, social, economical, material database from the very first step of the design process (Fig. 7).

Conclusions

Architects need to take into consideration the whole complexity of available social, economic and natural data while providing control on the decisions of the design process. This may only be achieved through the use of a properly modifiable, database, continuously fitted to the project, consisting of real, up to date, and comparable data.

In the project oriented database system (Fig. 8), the compilation of information - according to the project - starts at the beginning of the design process, with the collection of the basic data of social, cultural, functional, natural, structural, material, economical, technological information.

This way, the first architectural and structural decisions may be made through the evaluation of real parameters and the complexity of the measurement will be more secure. The applied systemized parameters will be controlled and consciously selected. Each data type must be evaluated from the very first step of the project.

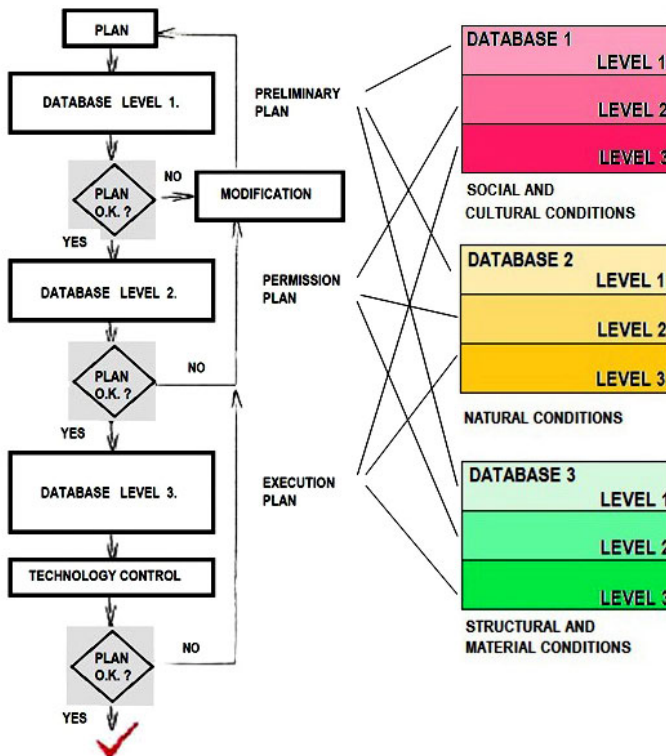


Fig. 8 Architectural design stages with project oriented database system.

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**Energy Efficient Site
Specific Planning**

**Environmental Database
of Local Architecture**

Architects and research

In Hungary architects generally don't do research and so they can be considered as end-users of various developments: materials, software, etc. They try to follow the life-long learning principle, they gather ever new information on new technologies and design techniques, but seldom come up with something decisively new on their own field of profession. Most practicing architects view their trade more like art than scientific engineering, and the buildings are more like creations than constructions. As such most of the architects' decisions concerning the major concept of a building are done rather on the grounds of personal feel and taste, than scientific calculation. Of course once the basic concept is given, experts from all fields join in and provide useful support for the developing the plans – they make the original concept 'work'.

On the Budapest University of Technology and Economics us, a group of architects have decided, that after so many years of material and technology research, finally the several century old design techniques need some renewal and reconsideration as well: the architects must leave the comfortable position of the end-user, and must take part in the common thinking on energy-saving. What if we could somehow incorporate energy efficiency into the earliest design phases? What if we could plan truly local buildings? What if we could design buildings which energy-wise make the most out of their given location? Could it mean that architecture could largely contribute to energy efficiency and energy saving?

After a few sessions of organized lectures and debates we concluded, that in order for architects to take the energy-consciousness seriously, they need precise, local data and some to that links the data to their plans: once we have the data we need a tool to visualize it (architects tend to avoid dry numbers), and when we can visualize our data, we need to make this platform interactive and simple, so it's easily accessible (Fig. 1).

The research team and program

As university professors we strongly believe in students and the quality work they can render. We think, that a university as a community should be a center not only for transferring knowledge, but also a center for the discovery of knowledge. Because of that we organized our research team like this:

1. Three major fields of focus were decided:
 - aspects of local climate relevant to building energetics;
 - environmental effect measuring systems and databases;
 - databases and simple architectural 3D visualization;
2. Each research topic got a separate team set up:
 - one professor / architect would lead the team
 - one senior / PhD student would administrate and help each team
 - at least ten students were assigned to each team.

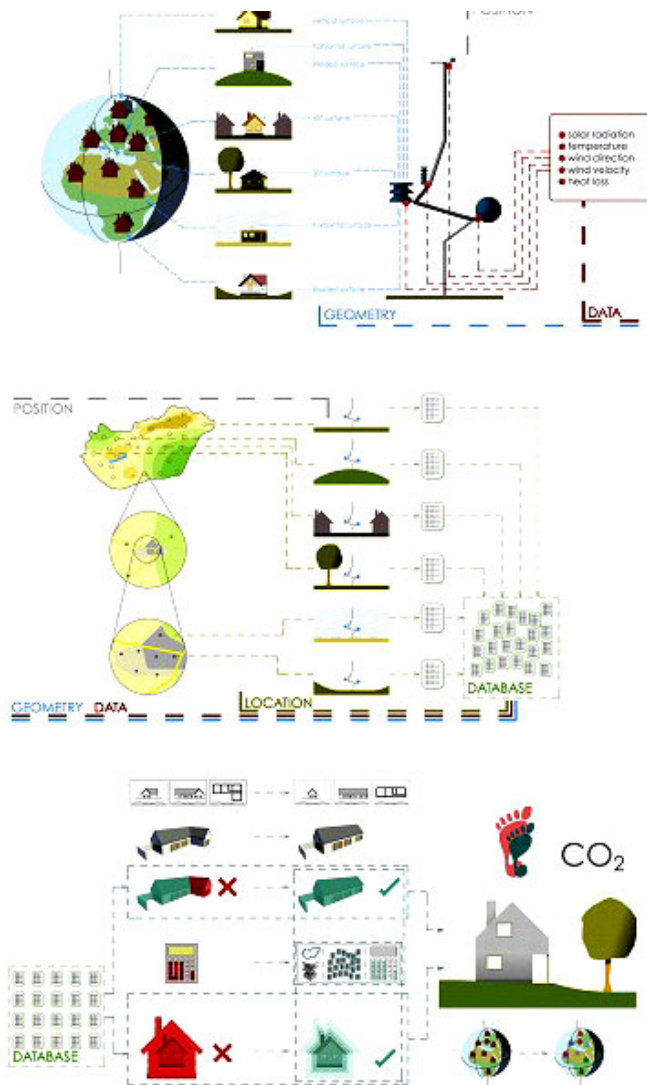


Fig. 1
Research plan and design process.

- specialist were drawn in when needed according their respected field of expertise: climatologists, geography experts, specialists on building energy management, measuring system designers, locksmith technicians etc.
- 3. We agreed on a tight work schedule:
 - each team would have their separate weekly meetings;
 - once in every two weeks we had a collective meeting presenting the progress of each teams' work;
 - once in every three months we had a written Research Report presented toward the university.



Fig. 2
Teamwork, building the measuring device.

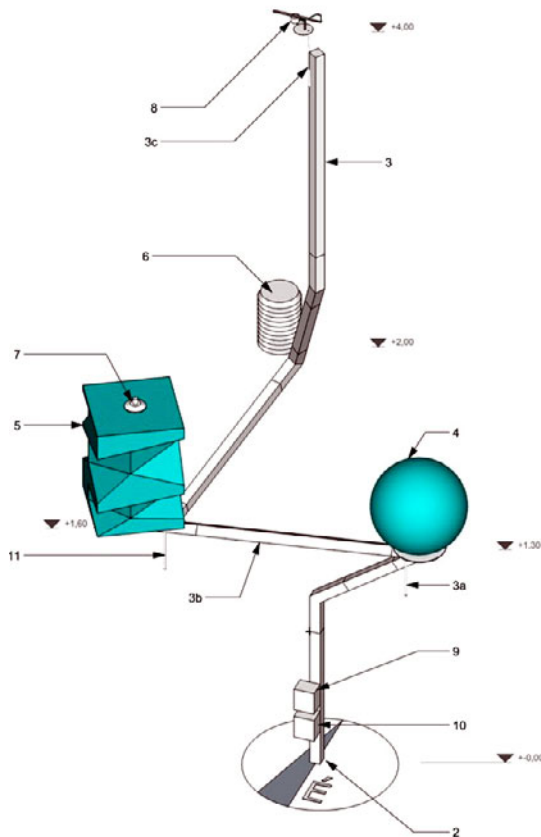


Fig. 3
Measuring system.

Energy Efficient Site Specific panning

We started our research in 2010. Two years have passed and although the research is still an ongoing project, we have quite a few results.

We have managed to develop and put to production a measuring system that specifically collects site specific data usable for building energetic simulation. It consists of uniquely designed data collectors (global radiation sensors, surface temperature meters, air temperature measuring device and wind gauge) data storage and transmission devices (Fig. 2, 3).

At the moment we have two of these devices working on a real site. We have been collecting data for four months now, so we have a nice database already.

We also have developed a small 3D software with a Google Sketchup engine. It can read the data coming from the measuring system, and also capable to import any .3ds model coming from the architects. Once the local environmental data and the planned building's 3D model is uploaded to the platform, our program makes the simulation, and renders the data onto the model. This way we can see and evaluate, how the building would behave, if it was built on the specific site.

At this point, after two years of hard work we could only make our system work, and yet it is very basic in most of its functions. In all aspects it could and should be improved: new sensors should be implemented, the data transfer definitely should be improved, the simulation program has to be probably rethought. We are also studying and analysing the data the system provides, because it seems obvious, that a few new formulas for building energetics are due as well.

And just to make the circle complete, this year we also started a new curriculum development for energy efficient site specific planning into which we naturally invite our students as well.

Notes

Ibuchim Ogunkah, and Junli Yang (School of Architecture and The Built Environment, University of Westminster) *Investigating Factors Affecting Material Selection: The Impacts on Green Vernacular Building Materials in the Design-Decision Making Process, Buildings* 2012, 2, 1-32; doi:10.3390/buildings2010001 ISSN 2075-5309 www.mdpi.com/journal/buildings/.

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Surface (Eco)Logics

**A geometric
and performative exploration
of 'deep surface' envelopes**

Introduction

Over the last two decades, digital design experimentations have pushed the envelope of traditional architectural models to define a new spatial condition that lies beyond conventional polarizations of surface and depth (Imperiale, 2000). Through multiple influences of philosophy, arts, mathematics and digital technologies, contemporary architectural theory and practice have contributed to the development of a new consciousness of “surface” that oscillates between multiple dimensions, from the flat representational space, to the deep architectural time-space (Taylor, 2003).

Embracing the new digital milieu, architects have explored the morphogenetic potential of flexible topological surfaces that integrate multiple design complexities and objectives into continuous yet differentiated systems. Soft transitions, mutations, gradient geometric transformations are some of the characteristics of smooth surface structures “that are capable of complex deformations in response to programmatic, structural, economic, aesthetic, political and contextual influences” (Lynn, 1993).

This new architectural paradigm has initiated a shift towards a multi-layered performative approach of form while academic research has also forwarded architectural experimentations towards the study of organic, biomimetic and morpho-ecologic structures. As Branko Kolarevic notes, “The sinuous, highly curvilinear forms could become not only an expression of new aesthetics, or a particular cultural and socio-economic moment born out of the digital revolution, but also an optimal formal expression for the new ecological consciousness that calls for sustainable building.” (Kolarevic 2005).

Moreover, current technological developments and broad use of advanced computational tools for the design, analysis and fabrication have enabled further investigations of complex surface geometries. At the same time large architectural practices internationally develop their own tools to tackle with such design intricacies. Gehry and partners have notably explored cutting edge computational design and CAD/CAM manufacturing processes (Shelden, 2002), offering loads of new knowledge to the architectural community. Other emerging interdisciplinary practices such as Design-ToProduction, Evolute, Arup AGU, have contributed to merging the knowledge gaps between architecture, engineering and computation, supporting thus the feasibility and constructability of such avant-garde architectures.

On Surface and Depth

Traditional architectural polarizations, such as inside/outside, are emptied of their meaning as architects are experimenting with topological ambiguities. As Alicia Imperiale affirms in her book *New Flatness: Surface Tension in Digital Architecture*, “Architecture, plastic, sculptural, voluptuous in its three-dimensionality is indeed reduced to pure surface. The absolute lack of depth signals the postmodern.”, thus architects are constantly repositioning themselves in relation to the issue of surface. Contemporary architectural discourse is seeking smooth transitions, continuous surfaces and flow. The Deleuzian approach to smoothness and interconnectivity of spaces together with the evolution of computational tools for architects have provided the theoretical and technical framework for the emergence of gradient heterogeneous spaces. Eisen-

man's interpretation of Chomsky challenges architects to distinguish between deep structure and surface structure, giving rise to a series of design experimentations, that range from complex models within the world of digital media to fabricated artifacts of diverse scales.

Though the effect and affect of the use of digital media in architecture is manifested in built structures of all scales, the main field offering opportunities for experimentation is that of pavilions, small scale shelters and exhibition installations. There are numerous examples drawn from the international architecture scene, negotiating with topological and functional transformations, gradient qualities of space, where surfaces mutate, transform and distort, responding to multiple criteria. In this realm the presented project, Water Ferry Terminals for Thessaloniki Marine Transport, tackles issues of aesthetics, performance, constructibility and adaptability; a single surface with encoded programmatic information (genotype) gives rise to four differentiated expressions (phenotypes) adapting to the environment, both context and orientation, yet sharing a common vocabulary and identity as a space of transition from the pier to the sea.



Fig. 1
Thessaloniki Ferry Terminal Proposal.

Morphological studies and variations

A mutable architectural form - a flexible surface - is proposed as the new urban type of the water transportation system of Thessaloniki. The distinct morphology of each of the four ferry terminals is a variation and diversification of such a programmatic surface structure. This 'generative' topological surface is differentiated locally and deformed to adapt to variable environmental, programmatic and structural requirements. The resulting curved surface looks like a 'seamless shell' that blends together roof and dividing walls into an uninterrupted building system that encompasses open and enclosed spaces. In this sense the surface contains conditions of depth, oscillating between flatness and depth.

The convoluting surface has as an effect of blurring boundary conditions mediating between diverse building elements and interior/ exterior spaces. This enables the organizational plan to allow for fluid mobility patterns while at the same time distinguishing the flows of inbound and outbound passengers.

One continuous surface is folded and transformed to accommodate spaces and program. The main characteristic of the composition is a three-dimensional element of local transformation, a central structural – sculptural element which is present in all variant forms of the Terminals and is recognised as the monogram “Θ” of the city of Thessaloniki when seen from several different points of view.



Fig. 2
Thessaloniki Ferry Terminal Proposal.

Performance and sustainability

The geometry of the shell was informed by its behaviour towards environmental conditions such as solar radiation and wind flows. Through simulations and evaluations the single-surface shell was transformed to meet multiple performance criteria. A diagram of prevailing winds' velocity and directionality was extracted so as to inform local and global transformations. The orientation and local climatic data propagated changes in the inclination, orientation and porosity of the surface until an optimised solution was found. Thus the vertical wings of the surface are oriented towards north-west so as to protect from the evening sun and prevailing winds. The resulting surface enables natural ventilation and solar heat control leading to lower energy needs for heating and cooling and thus to an optimised energy consumption.

An embedded system of louvers, shaped through local transformations of the wing (slicing and rotational translation), further enhances the environmental performance of the shell. At the same time the use of a reflective material and color reduces solar heat gain and due to the insulation properties of polymer achieves to control heat loss through the building skin. The single surface shell provides a great percentage of

shadow areas on the platform, ranging from 76,4% in summer and 50,7% in winter, as extracted from shadow simulations.

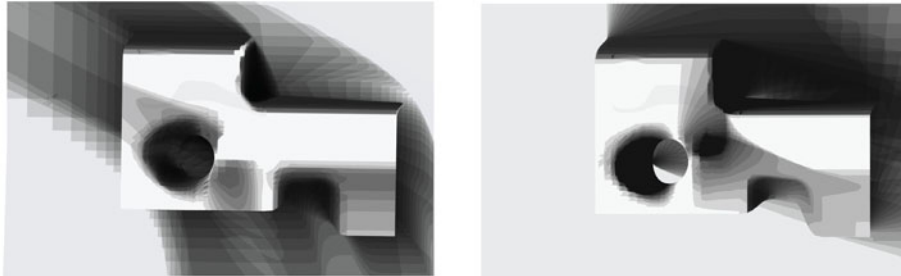
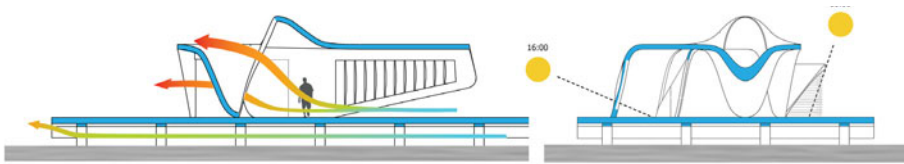


Fig. 3
Performance Diagrams.

Materials and construction logic

The structural logic of the shell is embedded in the morphogenetic strategy, thus giving rise to an integrated system of complex morphology and tectonics, conflating the structure and the skin into one element, a thick surface. The construction logic comprises of an internal metal structure of curved beams with external cladding of glass fibre reinforced polyester panels, a material broadly used in naval construction. The selection of materials aids the easy maintenance of the building and aims at a long-term economy of the architectural intervention.

The design and construction of panels has employed CAD/CAM techniques and methodologies. The geometric data is transferred to the CNC machine for the milling of moulds. Glass fibres are placed in two major stress directions and are impregnated in polyester resin. The urban furniture on the platform was designed in correlation with the shell structure, utilizing the same design principles of surface continuity.

However, as in most freeform structures, one of the main concerns is the rationalization of the geometry and discretization or panellization of double-curved surfaces. Manufacturing of such building elements in most cases requires the production of a custom mould for every single component. This inevitably results in an increased construction cost. There are various strategies and methodologies for geometric rationalization, each of them prioritizing different criteria such as planarity, uniform size of panels, employing triangle, quad or polygon meshes. A study of several currently available algorithms revealed the strengths and weaknesses of each approach, also

with regards to aesthetic criteria which tend to be overshadowed by structural or economical parameters. In the case of the Ferry Terminals, we opted for a surface division that would accentuate the smoothness of the shape while at the same time considers material costs. Thus, although panels are non-planar, most moulds are used for a minimum of 8 times till a maximum of 24 panels (with a small percentage of unique pieces per Terminal). This process involved both algorithmic tools as well as aesthetic criteria that are not easily encoded into an algorithm. Similar strategy was adopted for the internal structure, with both custom as well as repetitive elements.



Fig. 4
Bird View of Thessaloniki Ferry Terminal.

Conclusions

The proposal for the Ferry Terminal presented here achieves to respond to multiple performance criteria without compromising factors such as aesthetics, constructibility and cost. It is inevitable that the technological achievements of each era have their direct repercussion on design. This obviously affects the design product, though the major influence of technology lies in the design process. We are witnessing a major change in the way architects conceive projects. Parametric design tools enable architects to manage complex geometric forms, simulate their future performance and iterate morphogenetic strategies and analysis in order to reach optimised results. An architectural object evolves based on multiple criteria; the interaction with the environment, the deformations under load are investigated through simulations during the design phase generating data that through several iterations lead to the optimization of the architectural object. Architects have in their hands new powerful tools that can dynamically calibrate the design of the built environment to reach the desired performance.

The performance of a building relates to its capacity to respond to these criteria; a process of architectural optimization aims to create buildings that will offer protection from environmental phenomena, display structural efficiency and minimize material

use. A design investigation that employs advanced computational tools can lead to optimized forms with a direct repercussion on the cost of construction and its environmental impact. The performance of a building is evaluated through all the stages of its creation; from initial architectural design to its construction as well as the impact on the users when functioning. It is thus inevitable to introduce performance criteria during the first phases of morphogenesis (Symeonidou, 2010).

Dynamic design processes prove to be suitable for such an approach in architecture. Analysis tools such as CFD and FEA are no longer post-design evaluation tools; such tools can offer a quick evaluation of an architectural structure at an early stage without the need for excessive time consuming calculations. This can offer an understanding of the force distribution patterns, environmental modulation and train our intuition towards more performative design. Such platforms are common practice, mainly as a post design analysis tools. The aim is to incorporate such investigations in early design stages in order to understand and predict the repercussion of form on its future performance. "Determining the different performative aspects in a particular project and reconciling often conflicting performance goals in a creative and effective way are some of the key challenges in this approach to architecture" (Kolarevic, 2005).

Contemporary design tools are based on associativity between parts, interaction with environmental forces and emergence of forms. Advanced digital tools of design and fabrication have become accessible to architects and are converted in agents that are accelerating changes in the praxis of architecture. Branko Kolarevic affirms that "*digitally driven design processes, characterized by open-ended and unpredictable but consistent transformation of 3D structures are giving rise to new architectural possibilities*" (Kolarevic, 2003). Our generation is characterised by the transition from manual to digital design tools, initially employed merely as representation tools and recently involved in form generation. This paradigm shift was initially manifested in academic research, but is currently more than ever influencing contemporary architectural practice.

Aknowledgements

The project of Thessaloniki *Water Ferry Terminals* was awarded *Honorable Mention* at the Competition convoked by the Misnistry of Transport in 2011. Members of the design team were Anastasia Tzaka, Ioanna Symeonidou, Konstantinos Nastou, Eleni Georgiadou, Andreas Gkoumas. The project was exhibited in Thessaloniki Town Hall during 2012.

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**The Unscripted Man
inside the Scripted Box**

**Seamless integration
of spatial events
into the architectural design process¹**

Introduction

The human element in the design process

The discipline of Architecture has always been thought to evolve around the notion of space or, more specifically, physical space. Architectural designers have constantly been striving to accurately describe space through drawings, capture some of its three-dimensionality through scaled models or illustrate some of its materiality through photo-realistic computer-generated renderings. A brief look into the world of architectural publications will definitely pinpoint that space seems to be the ultimate architectural product. Nevertheless, a more careful examination will reveal that architectural design is greatly influenced by the human users that occupy the space.

Traces of the relationship between space and its users can be found in a wide range of literature. Starting from a broader, social point of view, French philosopher H. Lefebvre² as well as sociologist M. Castells both believe that physical space does not constitute a separated, autonomous entity but forms an integral part of society. More specifically, space is considered to be social product and for this reason is structured and developed according to the social and economical forces. Lefebvre goes even further to suggest that space is not only produced socially but at the same time co-shapes society by being an internal element of the social relationships³. At the architectural level, the first traces of the relationship between space and its user were identified and analyzed by C. Alexander⁴. According to him, the designed form and its context constitute an ensemble in which there should exist such order and harmony so as to avoid misfits. In the realm of architecture, the context is compromised by the human users that define the need for new buildings, together with the natural environment. The goal of the designer is not to describe just the form, but to succeed the perfect balance of the system form-context. The form is just the part of the system that he is able to manipulate. More recently, Oosterhuis⁵ suggests that people constantly send, receive and process information that interact with the building that they occupy and proposes ways in which the physical form could be more receptive to this information flow.

From the above it could be inferred that architectural design might be more accurately described as the manipulation of the relationship between human users and physical space rather than just the reorganization of physical form. It is the final equilibrium between the people and the space that will determine the actual experiential quality and the functional success of the initial design.

The human element in contemporary digital design methodology

It can be argued that although there is extensive literature regarding design methods and theories, there is not one widely accepted methodology that determines exactly how architects design buildings. Nor is it a goal of this paper to propose one. Through the history of architecture new design methods are introduced and others are considered obsolete, mainly based on the prevailing socio-philosophical context and the technological innovations of each era. Nevertheless, it is plausible to suggest that re-

regardless of the design method, the relationship between the designed space and the users is of paramount importance.

Contemporary architectural design is characterized by the emergence of many different digital tools and computational techniques that are exploited in many varied ways and interpretations: Parametric algorithms, generative scripts, biological models, interactive data analysis, intricate fabrication methods are all part of the current design paradigm that is characterized by ample diversity. This paper is based on the assumption that there is relative absence of human element within the realm of architectural digital design. There might be instances that user figures are inserted in renderings or animations but these usually represent more of a way to enhance the finished project than to further develop the design. Therefore, it can be argued that all the computational advancements of the last decade have enabled us to easily manipulate the scripted surface but there is not enough interest in the scripted user.

Importance of seamless integration of the human element in design

Architects initiate the design process when they get commissions from *people* in need of new spaces. The process usually ends when the buildings are finished and are occupied by *people*. In between these two endpoints, while the designer focuses on developing the project from the initial concept to the final construction details, usually the *people* disappear. They might be present in the mind of the designer but are usually absent from the physical manifestations of the design development (three-dimensional models, sketches). It is quite feasible to design and maneuver geometrical forms and surfaces but how is it possible to control and manipulate what *happens* inside them?

Before the emergence of digital design tools, it might have been impossible to integrate the human element into the design process. However, this is no longer the case. Computation has enabled architects to work with multiple layers of information at the same time. Regardless of the specific design methodology each architect uses, it would be beneficial to introduce a digital *human element* layer during the process. By having the advantage of visualizing and managing both the geometry and the actions that might take place inside a space, the architect is capable of making more educated design decisions. Hopefully, this might lead to better architecture.

Adapting to complexity and flexibility

The fore-mentioned integration of the human element into the design process is not an easy task. It has to happen in a flexible way that is relatively independent from a specific design methodology. Our goal is not to propose a new design method but to insert a new unexplored design layer into as many different existing design methods as possible. At the same time, the concept of human-space interaction introduces complex relationships that are changeable over time (in contrary to the physical form that is usually static over time). In other words, the designer is trying to loosely define how the user will interact with the built space from the moment that he approaches the space until the moment he departs from it. In order to avoid the overwhelm-

ing complexity as well as enable flexibility, it might be more feasible for the designer to manipulate only small but meaningful temporal parts of this interaction, instead of dealing with the human-space relationship in its entirety over time. An event is a term that can be used to describe actions between users that take place in a designed space over a certain period of time.

This relatively loose definition of the event affords interpretations that can limit the temporal complexity and offer flexibility both in terms of being methodologically neutral and adaptive to different scales.

A design tool that focuses on the useful manipulation of events

This paper proposes a new experimental digital design tool that will be capable of manipulating events during the design process. Regardless of the preferred design approach, architects that are familiar with computational design tools are using a handful of software to produce three-dimensional models of the designed geometry. The proposed tool has the form of a plug-in to the existing software and aims at offering another layer of functionality to what is already there. The goal is not to redefine or replace the current practice but rather to enhance and expand the design process by providing a seamless integration of the human element during the design process.

The existing generic modeling software (3D Studio Max, Maya, Rhino, SketchUp, Cinema 4D) are focused on providing various ways to model three dimensional geometric elements. There is no design intelligence embedded to these elements, no functional interaction between them and of course no way to control/visualize/simulate what *happens* in the model (the afore-mentioned events). At the same time there are other, more specialized, modeling software (Revit, Archicad) that offer the opportunity to manipulate not just boxes and surfaces but smart design objects like walls, slabs, doors and windows. These also lack the ability to control any human interaction that will take place in the space. The proposed tool comes as an expansion to the more simplistic generic modeling software and introduces a workflow that comprises of four design stages: Environment, Events, Elements, Evaluation.

Designing the environment

In every design task there is a clear separation of what already exists and what is the proposed intervention. Depending on the design approach of the architect the extraneous elements of a certain project can be as pedestrian and practical as the nearby existing buildings or as conceptual and experimental as the prevailing weather or data flow of a certain neighborhood. In any case the design tool offers the designer the opportunity to designate whatever he deems appropriate as "environment". As a first step, the introduction of the existing environmental elements creates the background or the backstage within which the actual design will take place.

Designing the events

The core functionality of the proposed tool lies in the second stage: designing the events. After setting the environment, the architect will be able to introduce what will

happen in the space. As mentioned above, flexibility is of utmost importance in order to create a useful tool that could accommodate different users with different design approaches. Therefore the technical interpretation of events can be manipulated in two different scales (event platform and individual events).

While working with large scale projects, event platforms are inserted as a diagrammatic indication of intended activity. They can be described as horizontal parametric surfaces that can hold certain functions. The user has the option of either choosing from a preset list of activities or creating his own. In any case, there are three key parameters that can be controlled for each event platform: *size*, *boundaries* and *connections*. The *size* parameter refers the actual physical area of the activity and it may include an indented dimension ratio. The *boundaries* parameter controls the desired physical characteristics of each boundary of the event platform and can range from open(0%) to closed(100%) with three intermediate states (25%,50%,75%). In other words the designer has the ability to indicate how transparent or opaque would like each event platform to be. Finally, the *connection* parameter enables the architect to create relationships between the different event platforms that are introduced.

In order for the event platforms to remain valid even as the designer works in smaller scales, the design tool uses the notion of individual events. The abstract activity that characterizes each event platform (for example: office space) is translated into specific actions of human agents that form individual events (human bipeds that sit in desks and move through the corridors). Naturally, these individual events can not cover the vast unpredictability of what might happen in a defined office space. However, by visualizing some key snapshots of indented human-space interaction the designer is able to insert a partial but vital design layer into his computational design efforts.

It is important to mention that in the creation of both the event platforms and the individual events, the designer can decide exactly how much control he/she wishes to have over the process. Some users of the digital tool might prefer to set all the parameters manually while others might prefer to control some parameters but leave others to the unpredictability of the software itself. It would be even possible for the designer to just set some parametric ranges and let the tool create algorithmic iterations of different event platforms and individual events from which he/she would pick the best.

Designing the physical elements

The third design stage is about designing the physical elements of the space. This is actually what already happens within the existing modeling software. Architects are visualizing their formal ideas by creating digital geometric entities. The crucial difference lies in the context: the digital model already has the environment and the events. The inserted geometry is placed in between these two other entities that are now visible in the software. It is up to each designer to decide how or if the events and the environment interact with the physical geometry of his project through specific linked parameters. For example, the boundary of an event platform could be linked with the

size of the windows of a corresponding wall. The more links there are, the more interesting will be the next stage of the tool.

Evaluation

After the completion of an initial version of all three elements (environment, events and geometry) comes the stage of evaluating the outcome. Usually, three dimensional models are evaluated by rendering them and critiquing them visually. In the case of events, there are two distinct types of evaluations that are both useful and can offer different points of view: visual evaluation and computational evaluation.

The visual evaluation uses animation from multiple cameras that follow the action in order to depict the way the events interact with the geometry. Instead of focusing on an aerial static perspective, the designer is able to evaluate action in space through the eyes of the users. At the same time, the software offers a computational evaluation of the model that complements the visual one. The design tool is capable of computing certain parameters and data that could lead to educated design decisions such as the ease of connections between event platforms, the relationship of each platform to certain elements of the environment etc.

The ultimate purpose of the evaluation stage is to create a feedback loop back to the design of the geometry and the placement of the event platforms. By introducing the human element during the digital design process the expectation is that there will be a more diverse and wealthier data pool that will lead to more educated design decisions. It is critical to mention that the usage of the events in the software has no intention of simulating or predicting the behavior of actual users. Instead, it only used as a creative tool that could improve the performance of the designer.

Conclusion

This paper tried to offer both a theoretical and a practical framework for supporting the idea that architectural design should be focused on the relationship between the human user and the physical space. After providing a general theoretical background, the importance of the seamless integration of the human element in the design process was analyzed. The notion of the *event* provides a flexible and practical theoretical construct as a backbone for the creation of an experimental digital tool that enhances existing modeling software. By placing the designed geometry in between the existing environment and the human events, this tool gives the designer the opportunity to evaluate these complex relationships both visually and computationally.

It is my belief that architectural space cannot be adequately described only by modeling and rendering its material form. Instead, it should be envisioned as a “stage” where events involving humans interacting with the built environment will eventually take place. The ultimate goal of this paper is to make it possible for architectural designers to evaluate and iterate their designs based not only on the form of the building but rather on the events and human actions that might take place inside it.

Notes

- 1 This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program “Education and Lifelong Learning” of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.



- 2 see Lefebvre, H: 1991, *The Production of Space*, Basil Blackwell, Oxford
- 3 see Lagopoulos, AF: 1993, “Postmodernism, geography, and the social semiotics of space”, *Environment and Planning D: Society and Space* 11: 255-278.
- 4 see Alexander, C: 1964, *Notes on the Synthesis of Form*, Harvard University Press, Massachusetts
- 5 see Oosterhuis, K: 2003, *Hyperbobies: Toward an e-motive architecture*, Birkhauser, Momenta

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**Explicating Intuition:
Iterative Modelling
of Elastomer Assemblies**

Introduction and background

Present day architectural affairs are often described as certain conditions. A brief look at my bookshelf results with an eclectic support of this observation: *Incongruous* by Kipnis in 1993, *Soft* by Kwinter in 1993, *Informal* by Balmond in 2002, *Evolutionary* by Frazer in 1995, *Responsive* by Price 1963, *Intensive* by Raiser and Umemoto in 2006 and last but not the least *Modern* by Corbusier in 1923, were all conditions attributed to architecture. In colloquial language we may use the term “condition” to refer to the state of things for something or someone, or describe the set of circumstances that give a full meaning only when considered as one interwoven whole. It is not an overly precise way of defining a certain problem or a research topic, but more of an intuitive or informed guesswork that can point the research in a certain direction. Two specific ideas or two conditions of architecture, the “Field”¹ and the “Network”² have formed a theoretical background for the research leading to this paper.

The term “Field” is introduced by Allen within the academic agenda and subsequently revisited in his seminal essay “From Object to Field”. In his words: “Field condition moves from one toward many, from individuals to collectives, from object to fields... Field condition is any formal and spatial matrix capable of unifying diverse elements while respecting the identity of each... dependant of local interconnectivity... The internal connections of the parts are decisive: overall shape and extent are highly fluid... Field conditions are bottom up phenomena: defined not by overarching geometrical schemes but by intricate local connections... Form matters but not so much the form of things as form between things”³.

Almost concurrently, in an essay and several lectures related to the study on the pre-history of virtual space, Wigley identifies Network as yet another condition, different and only distantly related to the idea of the Field. In his words: “Network is a condition, an elusive and invisible one that is new to architecture”⁴. He points out that the meaning of the term changes through time from the organization of human veins, through systems of rivers and canals, all the way to the immaterial things like groups of people. “The word slides seamlessly from biology to technology to society”⁵. He notes that for architecture too, its meaning is ambiguous and needs to be understood as more than the system of physical interconnections; “as the network of energy flow, information systems and an association between the visible and the invisible... Network is an effect that cannot be designed... it is something that does not have an interior or exterior... one cannot be inside or outside of the network... It is a system of interlocking elements with much resemblance with biological organisms”⁶.

Yet, the objective of this study does not rest upon mere visualization of these two ideas. Instead the experimentation is informed by them, and moves toward the materialization of complex and changing spatial conditions. The question posed is: Why are we lacking “Networks” and “Fields” in architecture? Key features of both concepts are then interpreted here as design challenges: Are these conditions material or purely organizational? Why is it difficult to build self-regulating structures? Why is geometric regulation insufficient to architecture? How do we design growth and accommodate for changing needs? What are the material repercussion of diversity and interconnectiv-

ity? In response, we identify the nature of the elastic deformation and corresponding material behaviour to start the investigation. The study aims at testing the alignment between material properties, model-building technique and novel spatial organizations, through the sequence of experiments conducted in the form of the workshops. The goal is to further develop the understanding of elasticity, not only as a material characteristic but also as a mechanism which could be subsequently transposed within the broader significance of architectural and organizational strategies.

Elastomers

The experimentation begins with the selection of elastomers as building materials, above all for their form-changing capacity. Their main characteristic is elasticity, the ability to withstand transformation and return to the pre-deformed condition; or the aptitude to adjust their structure according to external stimuli, for which elastomers promisingly fit into the ideas of adaptable architecture. In terms of their chemical structure, elastomers share more characteristics with fluids and gases than with solid materials which are most commonly used in the building industry. At the same time, by their behaviour, elastomers resemble soft biological tissue able to change and adapt far easier than mechanic constructs which have been the dominant solution in the realization of responsive environments, until the present day.

A brief look at the molecular structure of elastomers explains this resemblance better. They belong to the group of materials called polymers, characterized by long molecular chains (monomers) which are connected between themselves with covalent chemical bonds. Under the normal conditions these molecular chains are conglobated, but when external stress is applied they become parallel to each other, allowing for the elongation of the material⁷. Once the stress is removed, molecular chains regain their original configuration, relying on their covalent cross-linkages.

Elastomers are known to have a very low stiffness threshold and extremely high yield point, which define the magnitude of their elastic range. Other building materials behave elastically too, but less visibly since their reversible deformation range is significantly smaller. Many of them obey Hook's Law of elasticity which implies that strain is directly proportional to stress⁸. Consequently, mathematical description of a material's tendency to be deformed elastically is defined through the elastic modulus, equal to the ratio of tensile stress to tensile strain. For elastomers Hook's Law is applicable only approximately because their hard-to-control chemical structure is sensitive to temperature and loading rate⁹.

The knowledge of the reversible deformability of elastomers is based on the concept of displacement and non-linear relations through finite strain theory and difficult to predict cognitively in the design process. Therefore, throughout the study, manifestation of the elastic behaviour is condensed and observed via the elongation of the individual components according to the amount of stress imposed and relative to the material's tendency to be deformed elastically, or its elastic modulus. At first, the elasticity is employed intuitively in the form-making process, but throughout the experimenta-

tion, the understanding of its formative role gradually progresses from the approximation toward more explicit and parameter-based control.

Modelling technique

Proposed model-building technique is based on the additive assembly of components according to two parallel sets of principles. The first one is the algorithmic logic of consistent growth, whereby components are combined according to a geometric rule-based system; its logic is to be exhibited in a series of steps leading to the growth of the overall structure. The second set of principles is equally important but infinitely less apparent. It is related to inherent properties of the proposed building material, chosen for its intrinsic (chemical) structure that permits change and diversification between previously identical components. It only gains importance throughout the modelling process, as initial geometric logic becomes restrictive to further growth.

The approach is stochastic in its nature, based on easy-to-do techniques and hands-on engagement with construction materials. At the same time, direct and intuitive means of physical modelling are combined with the algorithmic logic to allow for the future transition from physical to computer-based modelling. "Algorithms are not necessarily dependant on computers....This distinction is very important as it liberates, excludes, and dissociates the mathematical and logical process used for addressing the problem, from the machine that facilitates the implementation of those processes"¹⁰.

4. Iterative methodology - the sequence of design workshops

Suggested design methodology is based on the iterative process whereby a designer anticipates development of the original idea through a series of prototypes. "Purpose of any prototype is to acquire knowledge which will be solely used for the construction of the subsequent model in the chain of iterations"¹¹. This approach can be deployed in various disciplines: for example, iterative development is also a form of software development methodology: it starts with an initial planning and ends with deployment with the cyclic interactions in-between¹².

All of the workshops, to be documented in the following chapters, have been interconnected and structured to form an iterative development sequence whereby findings from one workshop have lead to the structure of the subsequent one. This paper reports on the research by design combined with teaching goals. The study consists of four workshops that have taken place over a two-year period with the participation of approximately 60 architectural students.

Workshop "Inconsistencies v.01" October 2010, University of Belgrade

The first workshop in the sequence is conceived within the larger agenda related to one semester Design Studio Course for graduate students at University of Belgrade. The exercise was carried out with sixteen participants, in the short period of time and

with an aim to initiate thinking about adaptable spatial configurations and introduce appropriate techniques to be utilized throughout the semester.

Key features of both concepts, the Field and the Network, are interpreted as design challenges laid out for the participants. The suggested working method was founded on widely accessible elastomer-based materials and easy-to-do design techniques. Well known 'rubber bands' produced in vast quantities and used for various practical reasons, were designated components for the construction of complex spatial systems. Initially, the technique relied on the consistent use of the identical components to be multiplied according to some geometric protocol. Soon after, students were led to explore behaviour of the elastic material in order to enable adaptations of the designed structure according to an external influence. Elasticity is taken as the inherent property, which is transposed from the material characteristic into the organizational capacity of the designed structure.

As a result, the students produced a number of models which were able to respond to externally applied force by changing their geometric configuration and resuming their initial configuration thereafter. Models were made without scale, and appeared to be very diverse but could still be put into several categories according to the form of engagement between the structure and the external influence. Behavior of the matter and form confined to the reversible deformation range was documented within a time lapse sequence of photos.

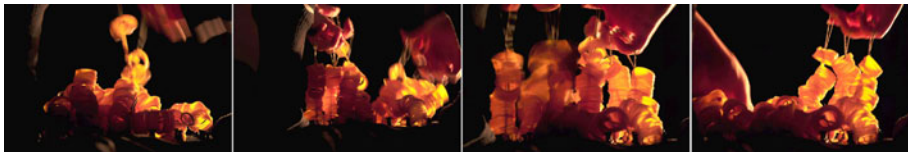


Fig. 1
Time lapse sequence "Inconsistencies v01", student: M. Tasic.



Fig. 2
Time lapse sequence "Inconsistencies v01", student: B. Gocanin.

Workshop "Inconsistencies v.02" July 2011, Architectural Association Visiting Programme

The second workshop was conducted at Tehran within the Visiting Programme, a platform created by the Architectural Association to further extend its educational setting through international engagement and collaboration with a diverse group of local

partners and schools. The agenda is built on the idea of the first workshop. The initial topic of the investigation was transposed into a different setting, of the city that has been a cultural and economic hub within the Middle East and has been historically renowned for its craft and manufacturing industry as well as its vibrant trade of goods and materials.

At the outset students were presented with the achievements from the previous workshop, and suggested to explore their own working methods of physical modelling using the very same material. Similarly to the earlier workshop, rubber bands were employed as modules within the framework of algorithmic based design techniques and once again students began by establishing the protocols of a finite number of steps and following a set of simple rules in combining the modules to create complex forms with visible structural and organizational logic. Soon after, resulting structures began growing everywhere in the studio, most often taking shape in web-like membranes spanning between the legs of desks and chairs. Within the first two days students had been able to achieve results similar to those that have concluded the previous workshop.

Thereafter, participants were suggested to combine their efforts by establishing five distinct research groups, each to tackle a specific design problem. Groups were assembled from students who have identified similar design topics in the initial charrette. Models continued growing and soon were not able to fit in the space of the studio and were subsequently moved to another, much larger room with a triple ceiling height. Two groups have opted to substitute rubber bands with other elastomer based components, while the three other groups decided to continue with the same material.

In the next phase of the workshop, participants were led to explore further material properties and potentials of elastomers as a means to build on adaptive design strategies. The focus of the workshop has shifted toward the study of material behaviour and resulting changes of the form. Elasticity of the material was used to generate structural motion in some experiments, or was essential to the design and construction process in other projects.

Research group (Amir Reza Esfahbodi, Abolhassan Karimi, Imman Shamedi and Mohammad Habibi Savadkuhi) with the project titled "Sway", was set to explore motion of two interconnected branching systems within the boundaries of structural stability. The project started off with the optimization experiments of two interwoven structures. Systematic and parametric studies were carried out on a series of rubber band models attached to a metal frame. Potentials arising from structural redundancies were used to set the system in motion. Throughout the experiment, structural behaviour was observed and recorded according to fluctuations of an external force (the weight of an occupant) introduced to the system. Adjustments to the overall geometry and number of connections between components, in conjunction with elastic nature of the material, were used to generate and gain control over the swaying motion of the structure. At first, the movement was vertical due to gravity, but with the struc-

tural and geometric tuning, motion deflected from the vertical path and acquired a twisting trajectory, resembling the motion in a ballroom dance.

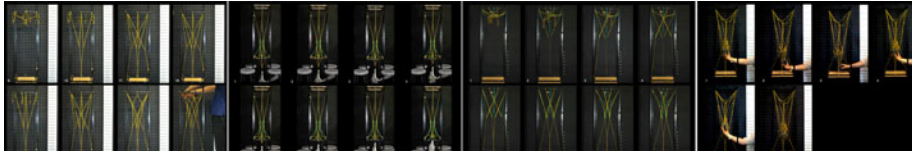


Fig. 3

Optimization experiments "Inconsistencies v02", students: A.R. Esfahbodi, A. Karimi, I. Shameli and M.H. Savadkuhi.

In the concluding stages of the workshop, two large-scale prototypes were produced. The initial rubber bands were replaced with similar but more durable elastomer components made from 100 mm wide strip. The second prototype, being the larger of the two, measured a full 11m in height.

In the early stages of the exercise, physical models were built without the notion of scale and only related to the abstract idea of the spatial organization and material transformation. Toward the end of the workshop, in discussion with the guest critics and students, we considered aligning already developed structural and organizational logic of the resulting forms with their utilitarian purpose. For instance, in relation to another experiment developed in parallel with this one, speculations were made if resulting models could become prototypes of a table or a chair design. In this specific project, the prototype has been developed and constructed to sway with the load of 100 kg or with the weight of a grown person, and therefore was able lend itself for the purpose of amusement. At the finishing ceremony, members of the audience were invited to sample the design, by swaying in the structure with amplitude of 3 m.



Fig. 4

Construction of the prototype "Inconsistencies v02", students: A.R. Esfahbodi, A. Karimi, I. Shameli and M.H. Savadkuhi.



Fig. 5

Testing of the prototype “Inconsistencies v02”, students: A.R. Esfahbodi, A. Karimi, I. Shameli and M.H. Savadkuhi, photo: Maryam Pousti.

In a separate project titled Clusters, the team (Khashayar Shafagh, Oveis Shahnaee and Ali Reza Shojakhani) was set to explore the role of material behaviour in the construction process of the web-like spatial forms. Model-building process was directly reliant on the elasticity of the material and carefully engineered bonds between the components in the form of the thin metal staples. The technique relied on the capability of stretchable bands to assume a myriad of different lengths to meet each other in space. Thus, construction unfolded gradually, through the establishment of the connections between the components. At first a number of smaller and almost independent structures were formed. They were identifiable by the apparent centrality and density of their binding components. Subsequently, these smaller structures merged together to form associations and larger entities. The rise of overall structural and organizational logic could have been observed according to the increase of the attraction and proximity between the components. Early models were made of several dozen rubber bands, while the number of components grew to several hundred toward the end of the workshop. This final model was never completed but the project offered a particular insight which has led to the conception of the next workshop, the third one in the sequence.

Workshop “Inconsistencies v.03” October 2011, O3one Art Space, Belgrade

Unlike the previous two workshops which were unfolding in the strictly academic setting, this one took place in the public art gallery visible to broader audience. The event was sponsored by O3one Art Space, an independent artistic initiative for promotion of projects from within interdisciplinary fields encompassing art, science and

technology. The workshop involved fourteen graduate students and was an integral part of the agenda related to one semester Design Studio Course at University of Belgrade.

Another point of difference with the two previous workshops is that this one did not require any individual research but rather a collective assembly effort. Yet, the result was not predetermined as nobody knew what it was supposed to look like. The experience gained from the previous experiments at University of Belgrade and University of Tehran, was converted into the explicit set of instructions leading to the realization of the single prototype. Knowledge and ideas gathered from the two previous workshops were now transferred into this phase of the project but there were neither drawings nor models produced prior to the construction process. Information was distributed amongst the assembly team members as a series of verbal instructions, structured into a design and build protocol.

This experiment was based on widely accessible resources and simple manufacturing techniques. Exactly, 12 kg of yellow rubber bands measuring 70mm in length and 5mm in width were employed as construction components of a complex spatial structure. In addition, approximately 8000 metal clips were used as joints between bands.

The assembly at O3one Art Space took several days to complete. The construction process started off simultaneously from five different points, from which a number of tentacles were established in relation to the structural considerations of the most suitable supporting points in the given environment. From the five points the structure grew in a systemic way, by the insertion of the new tentacle at the mid-point of the existing one. At first, the building strategy rested on a rule based system applicable to modular components while later stages of the construction relied on material properties to which overall geometry became subordinate.

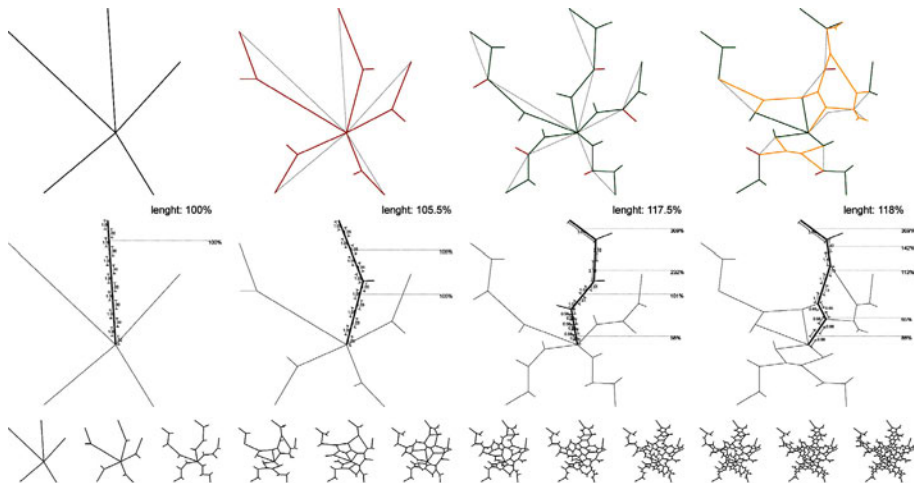


Fig. 6
Rule-based structure and approximate simulation of the material behaviour.

Material properties of elastomers were essential to the design and construction process. Elastic behaviour of the material has allowed for the use of construction technique based on the testing in real time. The length of each component and its connecting points are tested a in number of positions prior to determining the final one. At the same time, amendments were possible due to the 'clipper' joining system between the components. Such joints have allowed for an easy solution for the establishment of associations and disassociations between the constituent parts. Coupling between the flexible joint system and the elastic material behaviour was fundamental in the enabling of the direct way of working with spatial form, through the gradual sequence of adaptations and according to the process of decision making at the very local level.



Fig. 7

Prototype "Inconsistencies v03", photo: Ana Kostic.

The resulting model was based on the interconnectivity and local diversification. At any moment during the growth process, the overall stability of the structure was reliant on the multitude of local conditions. Throughout the modelling process, initially identical modular components react to tension forces and go through a process of gradual adaptation according to continually changing structural circumstances.

Workshop "Inconsistencies v.04" June 2012, Belgrade

Findings from the experiments of the three previous workshops, related to material properties and construction techniques, are synthesized into a site specific architectural strategy for a canopy design. The aim is to further develop the modelling technique which will establish a relationship between the elastic material behaviour and a boarder set of influences from the given environment. This workshop was meant to

take place at the abandoned and roofless construction site in Savamala, part of the city dotted with dysfunctional buildings of vast potential. One of the goals set, was to activate this space through public use. Construction of the full-scale model could have been the first event to engage public at this location. Site possession, for the period of two weeks has been granted by the local municipality, its current owner. Unfortunately, just several days prior to the beginning of construction, workshop has been cancelled and moved to another location for safety reasons.

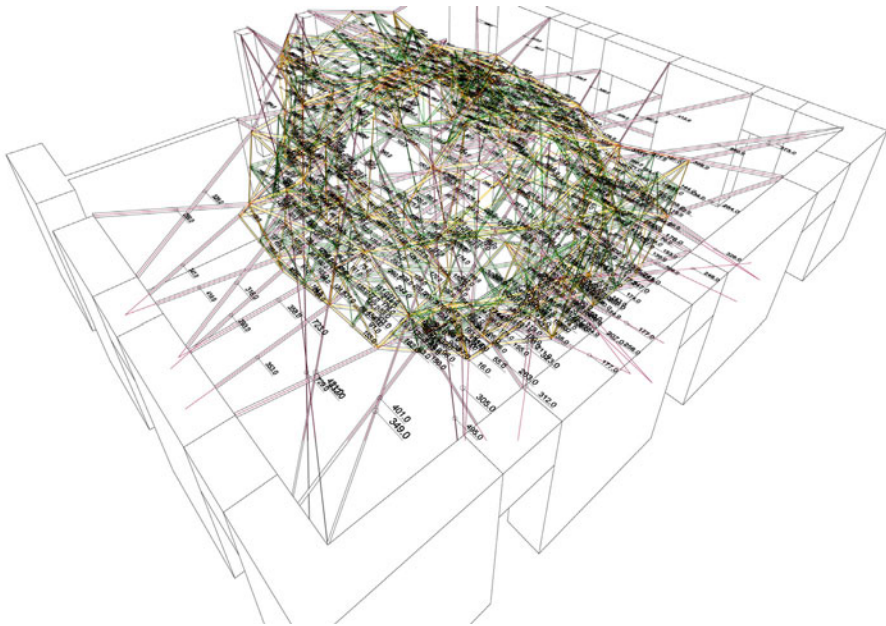


Fig. 8
Cost calculation and quantity take-off.

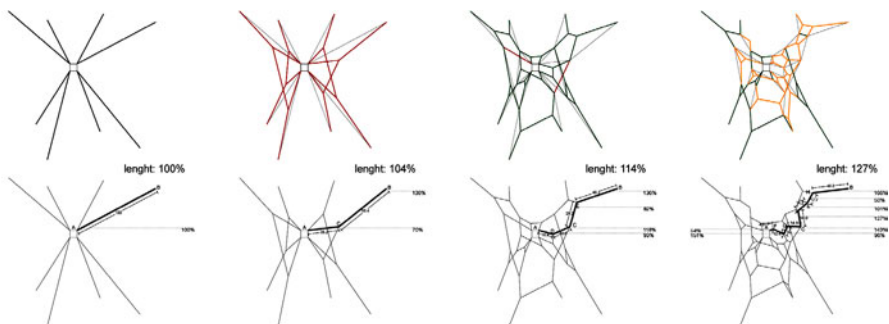


Fig. 9
Rule-based structure and approximate simulation of the material behaviour.

Novelty, in comparison to previous workshops in this sequence, is in the use of the computer model and more accurate simulation of the construction technique, which is then a planned, collective effort. The chosen material is the elastomer-based strip, measuring 70mm in thickness. The calculated total length of required elastic is 1,853,830mm (1.85km). The building technique is based on the growth protocol with subdivision principles. It is comprised of the initial establishment of spans between the centrally positioned columns and remains of the perimeter wall found at the site, and three subsequent steps of their interpolation which lead to the establishment of more dense structure. Once again, the elasticity of the material is considered essential to the construction technique.

Evaluation

Lessons learned from the first workshop have confirmed the prospects of the elastomers in building highly complex, responsive and differentiated structures. As anticipated, a rule based technique proved to be an efficient way of modelling growth. Resulting models have captured some characteristics of the Network and the Field, two theoretical positions identified at the beginning of the study.

Points taken from the second workshop include the need for prototypical full-scale modelling and provide the confirmation of the capability to generate and control motion within the realm of structural stability at this scale, and with the use of suggested material and technique. At the same time, more insights were gained on the design and model-building technique capable of unifying multitude of diverse elements into a single structure.

Knowledge gained in the third workshop extends the architectural understanding of the Field and the Network conditions. Interconnectivity and production of locally different conditions are the key characteristics of the resulting model. At the practical level, modelling technique has made progress in the structuring of the growth protocol to include a multitude of participants. The construction technique has evolved to allow for real-time testing.

Preparations for the fourth workshop have shown more reliance on the computer model. Previously, an intuition-based approach to modelling is replaced with more explicit control of the geometry and the approximate simulation of the material behaviour. In turn this has allowed for better cost calculation and more comprehensive preparation of the construction process.

Synthesizing of the algorithmic logic into the process of physical modelling has been central to all of the described workshops with an aim to enable transition to computer modelling. Parametric control of measurable properties of the material and observation of the rules of the physics, prepares the physical modelling technique to be translated into a more efficient and economic way of modelling based on computer simulation. The next iteration of the computer model aims to introduce real-time elastic performance of the material and structure into the rule-based logic of the growth process, through the elongation for each of the components relative to the stress

applied and the elastic modulus of the material. The study continues with further alignment between the material properties and model-building technique, yielding knowledge applicable to the design and construction methodology and which can be employed at different scales and for different reasons, such as those related to dimensional tolerances during the construction process, or at very different level, to those more strategically oriented toward spatial organizations of cities and buildings.

Conclusions

The sequence of development throughout all four workshops reads as an attempt to explicate the intuitive. It provides the means to handle cognitively complex processes by moving from the simple fascination with the material toward the capability to predict, simulate and employ elastic behaviour within the design process. This way, the hard-to-control nature of the material is not restrained but given an instrumental role in the form making process. It becomes a self-regulating mechanism, enabling local variability through continual adjustment of components during the growth of the assembly.

The intrinsic structure of elastomers, comparable to that one of fluids and gases rather than solids, taps into the structural and consequently organizational properties of the overall form, reaching far beyond purely geometric regulations. The understanding of the elasticity, as a structural change at the material level, becomes relevant within the boarder significance of architectural strategies, initially identified within the Field and the Network conditions. Elasticity then becomes a measure of responsiveness, a capacity of continuous adjustment according to changing circumstances.

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The documented study combines research and teaching efforts; it is planned as a collective effort and would not be possible without contribution from my associates, Milutin Cerovic above all, and students. Following is the full credit list:

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Inconsistencies v.04: Djordje Stojanovic (assistant professor), Milutin Cerovic (teaching assistant), Milan Katic, Milica Tasic (assistants), Nikola Milanovic, Ivana Radovic, Katarina Mercep, Marija Pop-Mitic, Danka Sijerkovic, Jovan Pucarevic, Dea Kolacek, Milos Simic, Emilija Zlatkovic, Dusan Tasic, Ana Todosijevic, Marko Vukajlovic, Nevena Bjelakovic (students).

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Notes

- 1 see Allen S. "From Object to Field" *Architectural Design* Vol 67, no 5/6, 1997, p. 24.
- 2 see Wigley M. "Network Fever" *Grey Room #4*, 2001 p. 82.
- 3 see Allen S. "From Object to Field" *Architectural Design* Vol 67, no 5/6, 1997, p. 24.
- 4 see Wigley M. "Network Fever" *Grey Room #4*, 2001 p. 82.
- 5 Ibid.
- 6 Ibid.
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**The Digital 'Soul'
of Smart Materials -
Creating Programmable
Environments without Parts**

'Materiality' in the digital culture

To begin with, one needs to investigate the definition of the word 'digital'. During the past 10 years, the digital discourse has presented a variety of contexts within which one could search for definitions. From a scientific perspective, a digital system is able to handle raw data by assigning to it discrete (discontinuous) values in order to file it. "Although digital representations are discrete, the information represented can be either discrete, such as numbers and letters, or continuous, such as sounds, images, and other measurements."¹ On the other hand, non-digital (or analog) systems use a continuous range of values to represent information. The word 'digital' is most commonly used in computing and electronics, especially where actual, real-world information is converted to binary numerical values. It can also be used to describe a process in which information is deconstructed into tagged and valued little pieces that can be formed in various ways, either to be analyzed, manipulated or represented. The core of this idea is the breakdown of continuous sets of data perceived by human cognition to a seemingly limitless body of values.²

The first digital tools appeared as simple data processors, going through endless streams of disconnected values, such as product prices for the market as well as for statistics. This task marked the birth of computation. More refined machines emerged during the World War II, when the Allies were struggling to break the German codes. Since then, the ability to simulate and compare revolutionized the industry, leading at one point to the adaptation of these early electronic tools for designing purposes, although mainly for mechanical assemblies. Later on, sophisticated control systems emerged, introducing automation in production and smoother operations. The digital tools became *media* the moment they were able to relate disconnected values, creating entities that resembled the analog. It was this step that made them popular, because from that time on, they became understandable. The products seemed smooth or continuous to the naked eye and only through an extensive zoom mode the pixel effect was revealed. From a Husserlian point of view, if it looks smooth/analog then it is considered as such. This is the moment when the digital definition became blurred.

In the most common architectural context today, the word 'digital' is used mainly to describe design and manufacturing processes and techniques. The architectural representations, on the other hand, follow an analog format in order to communicate sets of continuous data to people. So, it seems that the macroscopic product is far from the indigenous nature of *digitality* and can be misleading regarding the ways the production of space and subsequent materiality is affected. Design drawings, used by architects as their basic communication tool, and buildings, as the principle materialization of their work, are actually analog (continuous values of information), so how exactly did the 'digital' affect the practice and where can this lead?

Antoine Picon argues that a digital culture permeates all aspects of contemporary design³. A strong believer of the link between available technology and the production of space, he sees contemporary architecture as a process, either directly linked to design, or tangential to it as the social networks increasingly affect it. The ability of an

architect to engage the context and express the concept is deeply interwoven with the level of “digitalization” in society and culture.

At some point, the ‘digital’ part of architecture evolved to include the ability to manipulate surfaces. Every equation has a responding surface, so mathematics opened up the way to explore and research novel explorations of building envelopes and interior partitions. The “science” behind the production of such spaces marked the birth of parametric design and algorithmic processes. The infrastructure was provided by dynamics, metaphors of physics related to social activities and environmental characteristics that can be applied to “soft” surfaces and change their shape according to the impact.

This direction seems closer to the original notion of ‘digital’ than the common design, render and photorealistic practice which actually just substituted the analog methods of ink on tracing paper and the colored perspectives. In order to conduct research in the parametric architecture field one needs to breakdown data: to analyze relationships of conditions and elements, to create a matrix of connections and to set up morphing tools along with an assembly logic. It is a breakdown-reassembly method that emulates the mathematical model. This model, even though it is comprised of inter-related pieces, it seems open-ended with unlimited possibilities to be arranged, making the design process easier and less deterministic. Moreover, it marks the way from a copy-paste-delete-save practice to a form-generating research tool. New tools bring new methods, which in turn lead to the creation of new forms. Especially nowadays, omni-connectedness leads the trends and disperses processes that increase performance and generative abilities, flooding the world, leading to a new international style. Along with that comes the promise of the ability to build these intriguing forms with a nearly reasonable cost. The fact that the Internet is replete with ‘How to build a home-made CNC machine’⁴ tutorials is making this promise valid.

Immersing into the *scaleless* to find the *seamless*

So what is the next step? This paper argues that it is a fusion between the digital and the real. It is a research direction that aims to integrate the logic of identifying crucial elements and their parametric dynamic relationships, making simulations in a virtual environment and implementing the desired outcome through live actuators in real-time. The necessary tools to proceed in that direction are well under way. From the software perspective, sophisticated simulations of various time-related phenomena are already available, made possible and augmented by the increasing processing power. This has a direct effect of simpler generative processes that adapt better to given conditions and enable easy, parametric, dynamic form-finding. The produced form, being dynamic, allows spatial transformations driven by the dynamic effects. While software can simulate the behavior of the necessary elements to maintain the dynamic relationships between the parts on screen, kinetic systems can provide the hardware to physically create active structures. The prevailing question is whether architecture can proceed with this by itself.

The interdisciplinary, or, even better, the multidisciplinary approach is crucial. There are endless paradigms all over history of how available technology influenced the

notion and the essence of volume and surface. From the Parthenon, to Da Vinci, to Fuller and Prouvé, technology mixed with (or produced by) ingenuity pushed the envelope further with new attributes, both phenomenological and ontological, that consequently created new 'traditions'. In the 20th century, technology changed society more radical than ever before, leaving philosophers and politicians trying to keep up. Technology started to promise things beyond the regular, and in order to deliver, the time of polymaths, momentarily in time interrupted by a time of specialists, seems to be returning as group specialists form a *neo-polymath*. This emerging multiplicity requires more and more sophisticated data processing through a flexible medium that will connect different inputs to a commonly understandable output.

In architecture, a field widely known for its lack of funding for research, the experimentation of multiplicity begun in the hands of modest thinkers, such as Frei Otto, mainly with analog means but with digital logic. These experimentations led to incredible, for the time, architectural products and set an example valid until today. Many projects that are currently considered as cutting edge, such as Felipe's and Truco's HybGrid,⁵ are heavily based on Otto's experimentations, in this case the Movable guyed mast.⁶ What is different today is the fact that most of these experiments are conceived and created at small scales or as parts of a larger assembly. The intricacy and the multiplicity of their full-scale application are beyond the knowledge base of any practitioner or researcher of architecture and so a multidisciplinary approach is imperative. If architects wish to evolve, they must be able to see things from other perspectives.

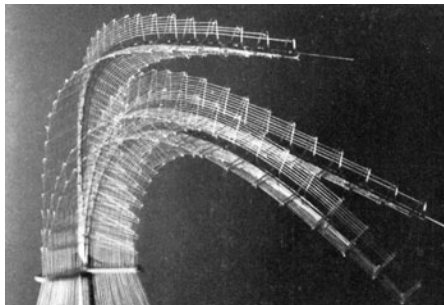


Fig. 1
Frei Otto: Movable guyed mast (1963).

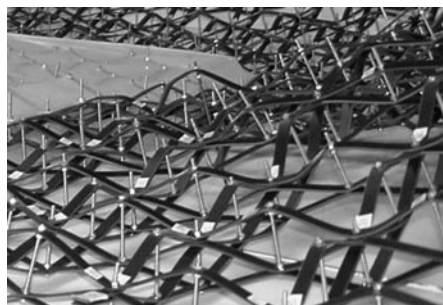


Fig. 2
Truco and Felipe: HybGrid (2003).

As architects 'see' things phenomenologically, meaning they perceive features in the macro scale, they have to understand better the mechanisms that affect these features and, more importantly, the fact that the mechanics of it are located on the smallest scale. The geometry and the attributes of a material's surface and consistency are the key to how it looks and performs. The ways to intervene with precision to these characteristics are two, either through molecular manipulation or through organic processes. With molecular manipulation one can already create high performance materials, like carbon nanotubes or the much-promised *graphene*, as well as smart materials that can lead to lighter, stronger, responsive elements just through their molecular arrangement and its dynamics. The bioprocesses, on the other hand, are

either performed through enzymes, like Nexia Biotechnologies' *BioSteel*, or through biofabrication.

Bio-fabrication, being currently in its first steps, is a method where living organisms, such as bacteria and viruses are employed to produce a framework for macro-structural fabrication for architecture, as a pure bottom-up procedure. This research is the current epitome on parametricism, algorithmic processes and multi-disciplinarity. The work of Flynn, Lee, Peele and Belcher on viral fabrication employs viruses to produce 'building blocks', such as collagen, that can be assembled to construct larger elements.⁷ The technique can be employed, when fully developed in the future, to produce a variety of materials that will exhibit any designed effect and behavior. Furthermore, if necessary, it will have the ability to mutate to a different variant of the material. Finally, it will self-repair itself continually and even fine-tune its performance. The 'tool' for that is a genetically engineered retrovirus that can perform all the aforementioned tasks as a minuscule worker. This role is played by the *acetobacter xylinus* bacteria on the work of Araya, Zolotovskiy and Gidekel. The A.Xylinus produces cellulose by consuming sugar, found in many industrial disposals. By controlling genetic characteristics and physiological parameters, the team, with the help of genetic engineers and biologists, achieved to control the creation of structural elements in different scales, even for architectural use. They finally conceived and created a crude "Biological 3d Printer"⁸ based on the organic nature of the 'material', which leads to distinct responses according to stimuli that either act as attractors or repulsors, allowing for different densities and forms.

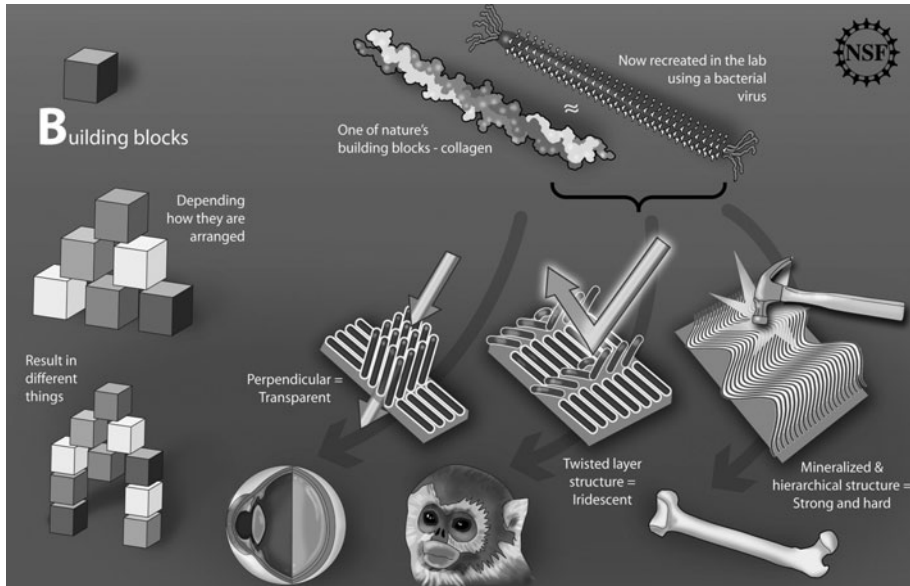


Fig. 3
Lee and Deretsky: Viruses into molecular Legos (2011).

This research direction opens up the way for a strong discourse on the direction of how the design techniques will evolve and whether hybrids between mechanical and genetic engineering will emerge. The 'group of specialists' in this research direction will enhance every aspect of the design profession, including the areas that deal with the materiality of the produced space and affect its development along different approaches that vary according to scale and relation to '*digitallity*' (pure digital character). Following there are four design approaches presenting different ways in which materiality is expressed in the digital era, according to scale, surface, volume and depth and their phenomenological value, that plays a critical role in the way architecture communicates with people.

The macro effect approach: Creating smart processes

This is the standard and usual scale in which architects, and all other design professionals, operate. The characteristics acquired from the digital era are mainly pinpointed in the direct fabrication process that leads to a broad offering of mass-customization. The key feature of this process is the analysis of the important attributes of the materials and the building components used in a specific project as well as their classification to wider groups that share similar characteristics. These parts can be further processed to change some of their features, within a certain degree, and then assembled, sometimes in more than one ways, to provide a kind of uniqueness. This leads to 'mass-individuality', a paradox concept that fits contemporary society. Based on the digital logic, the complexity of any design product originates in the variety of the assembled 'discrete' parts and can be achieved easily. The drawback, on the other hand, has mainly to do with the high maintenance requirements of the equipment and the inevitable realization of the similarity of the output. Additionally, the small interdisciplinary requirement leads to limited evolution of the processes. Finally, regarding the overall digital nature of the processes and the products of this approach, it can be characterized as '*externally acquired digitallity*', meaning that it is not inherent in the distinct parts used and it is gone after materialization.

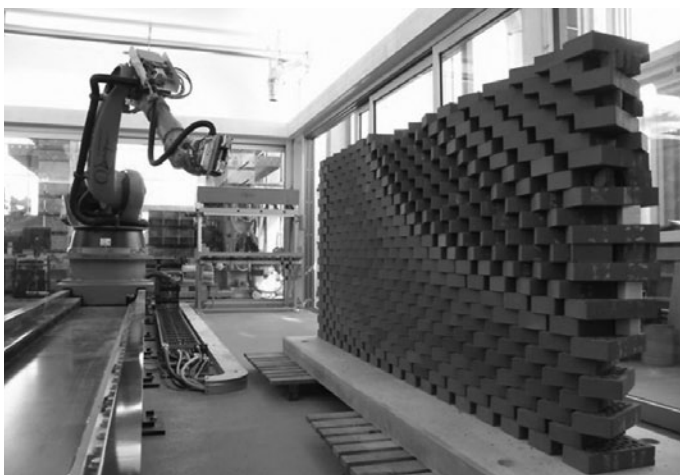


Fig. 4
Oesterle and Knauss:
Robotic brick stacking (2006).

The meso effect approach: Creating smart assemblies

The key element in this approach is the assembly of parts and the effects of their connectedness that lead to emulation of behavior. Smart assemblies are usually formed by the repetition of simple systems that act on the principle of *emergence*⁹ to create the impression of intelligence (or more precisely pseudo-intelligence). The smaller scale indicates that the breakdown of parts goes to a more detailed level. In this category, the pieces used to comprise the whole are more sophisticated and have extra parts, such as mechanisms or electronics that give them additional attributes. In actual space, the pieces are connected to one-another through a dynamic parametric relationship, like in the Aegis Hyposurface project by dECOi that acts as a responsive surface.¹⁰ By connecting together a large number of pieces with small complexity, one can create assemblies with increased phenomenological complexity, reducing somewhat the sense of 'complex simplicity'.¹¹ High maintenance is still an issue here, presenting an even bigger problem than in the former macro effect approach. Furthermore, there are times when the complexity may seem simple or limited, losing any benefit from the interactive attributes. Regarding interdisciplinarity, this approach is well dependent upon other fields, such as electronic engineers and mathematicians. The digital signature in this case is also external, but it is more vivid as it remains evident within the actual use of space, rather than be limited to the design and manufacturing process.

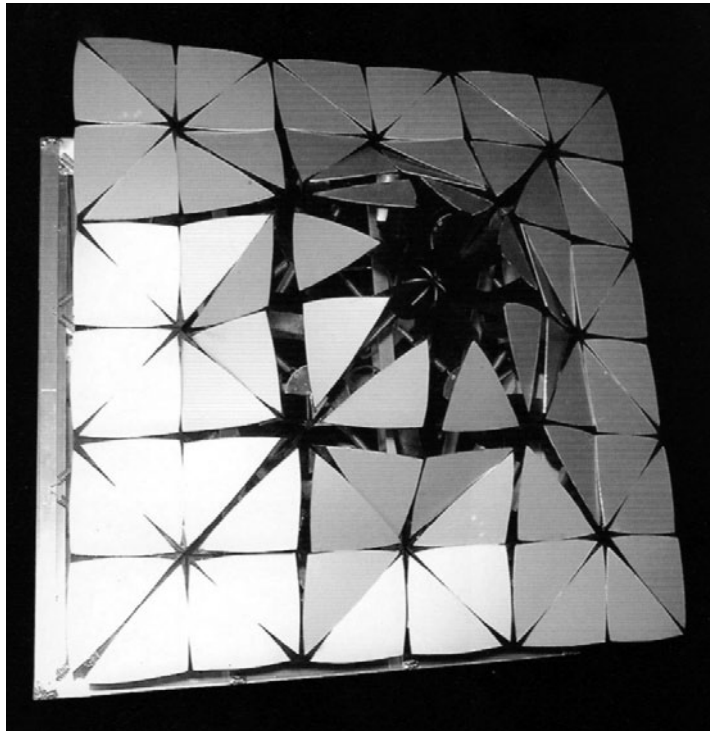


Fig. 5
dECOi: Aegis Hypo-
surface (1999).

The micro effect approach: Creating smart materials through molecular programming and micro construction

This scale forms the threshold where future innovations will emerge and the true digital context will fuse with real materiality. The micro scale approach is already a case and even though it has few applications to exhibit, it presents a growing number of researchers and practitioners that wish to implement it broadly. The creation and application of smart materials and self-sustaining micro structures, such as MEMS (Micro-Electro-Mechanical Systems),¹² maintains all the benefits of the previous scale examined while additionally the required connectivity is found and regulated even in the molecular level and it is seamless between the parts. This reduces the main drawbacks in maintenance and complexity, a problem that affects critically the two previous approaches. Overall, responsiveness and pseudo-intelligence is present, emerging from a truer 'simple complex' system. The approach is heavily dependent to other disciplines, keeping a continuous track with every relevant development in order to be enhanced. Furthermore, *digitallity* is inherent as the mathematical relationship model that affects directly discreet elements and creates a whole is thought of, designed and integrated directly in the material.



Fig. 6
Glaister, Mehin and Rosen:
Chronos Chromos Concrete
(2008).

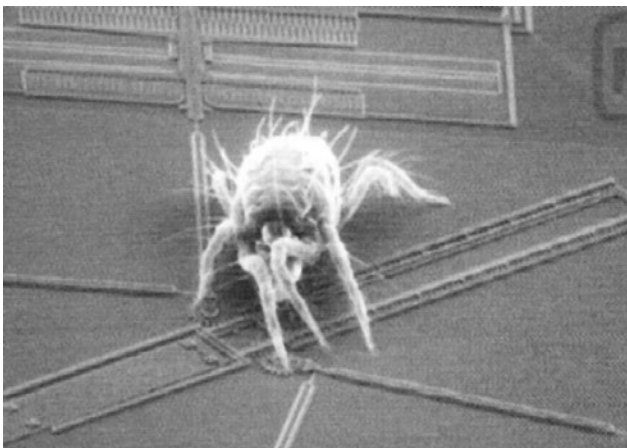


Fig. 7
A spider mite on top of a
MEM's device surface.

The nano effect approach: Creating smart science

Evidently, this is the more intriguing and the most futuristic approach while, most likely, it will take a lot of time for it to be widely applied. Its basic characteristic is that the manipulation of matter is taking place in the material's core, allowing not only for better programming but also for fabrication within the core of it all. The first steps have already been made in the form of creating ultra-performing materials such as graphene, or living organisms engineered to act as small assembly factories that produce matter bit by bit. The abilities extend in the creation of small bio-mechanical hybrids or tiny cyborgs that can act as the smallest autonomous controllers combining sensing, actuating and computing functions. The most obvious benefit of sophisticated construction at this level is the structural perfection that comes with it. As a direct effect, the materials and structures produced are lighter and sturdier. Furthermore, one can increase the design performance by augmenting specific attributes. This approach is the epitome of multidisciplinary and inherent *digitallity*. It is the true digital in the heart of matter.

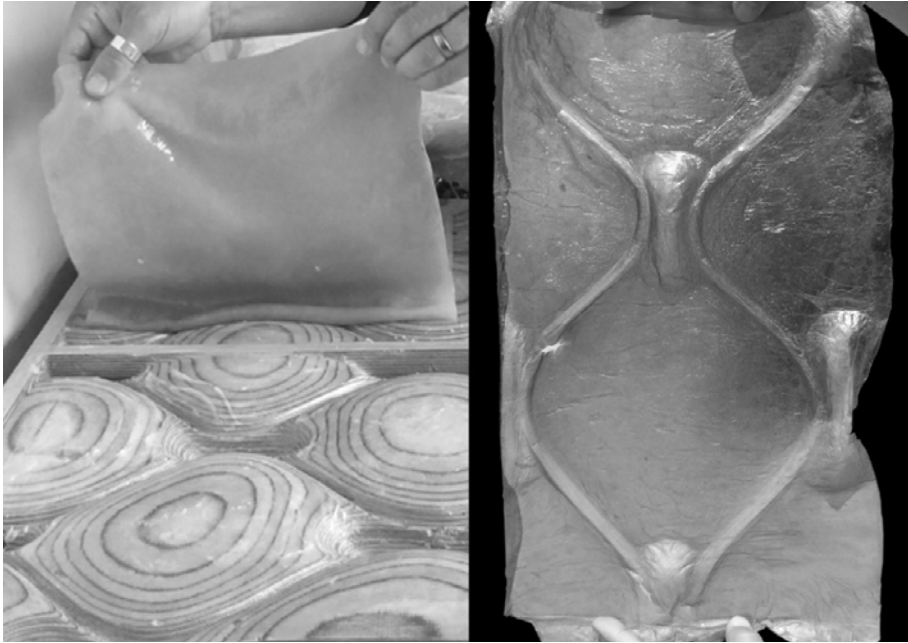


Fig. 8
Araya, Zolotovskiy and Gidekel: Bio-Fabrication (2012).

Digital can be in the heart of architecture: Materiality goes deeper and ...alive

The micro and nano effect can be described as the invasion of digital culture/logic in the heart of matter. It gives new meaning in the sense of depth. The interior/consistency of matter, and not only the surface or its shape, is affected directly. A design

product will be then described as a whole comprised by its smaller pieces that all carry the ability to have different values, either within their material characteristics or within their position in space, in relation to one another. The designer will also be able to alter these values, according to the conditions that affect them. Quoting Aristotle, this means that the whole will be more than the sum of its parts, since the 'pieces' will always be in a state where they will 'behave' according to the surrounding conditions, and produce many variations of the whole, while continuing to retain their parametric relationships.

This requires another level of design mentality, an evolution in which the architects' talent is pushed to a somewhat different perspective, not focusing on solving the 'numerical' part of the composition, since functionality will be granted¹³ and aesthetics will be surpassing the strict geometrical influence. The architects' intuitive nature will design experiences driven by the human-centered approach of "what people feel in our designs". In order to achieve such a design goal, scientists from other domains are required, like material scientists, programmers, physicists, biologists, psychologists, artists, game designers, even sci-fi engineers. Architecture needs their input to be able to design and control extreme (as regarded today) parameters that affect every aspect of its projects, from the overall human sensation to the core of the matter.

Table 1

How digital materiality affects design.

- Surface becomes responsive tactile and visual
- Volume acquires a self adjusting density
- Depth creates an "animated" interior that senses and responds
- Space communicates with its users

So, inevitably we come to a point where we need to reiterate the question of "what next?" Well, architecture always tries to visualize the abstract, represent it and bring it to life. In this sense, contemporary tendencies lead to a complexity that requires inherent digital qualities to achieve the design of experiences and sensations rather than a static building shell. Design methods must implement open-source logic to the built product, to accommodate changing requirements while retaining critical relationships, in a *live* parametric matrix, by integrating self-organization abilities on semi-individual components. This means simply, that the design object is expanded to reach the heart of matter. This is where we can find the true influence of the *digital*.

Notes

- 1 <http://en.wikipedia.org/wiki/Digital> (retrieved 16/10/2012).
- 2 This process was most provocatively depicted at *The Matrix* movie (1999). The streaming flow of data in the green hue showed, more vividly than ever, the breakdown of everything analog to discontinued yet connected fields of data pieces, manifesting that everything can be

- digitized in a world of new “perspective”. Surface and depth were merged in one entity while limits and stereotypes faded.
- 3 Picon, A., *Digital Culture in Architecture: An Introduction for the Design Professions*, Birkhäuser Architecture, 2010.
 - 4 <http://buildyourcnc.com/default.aspx> (retrieved 21.10.2012)
 - 5 Truco, J., & Felipe-Marzal, S., “HybGrid: From Form Generation to Form Adaptation”, in: *Proceedings of Responsive Architectures: Subtle Technologies*, Beesley, P., Hirosue, S., Ruxton, J., Tränkle, M., & Turner, C. (eds.), Toronto: Riverside Architectural Press, 2006, pp. 116-119.
 - 6 Frei Otto is famous for his extensive experimentation on innovative building shells and structural systems as well as on flexible, adaptable architecture, all conducted with the available analog means of the ‘60s and the ‘70s in the Institute of Lightweight Structures in Stuttgart.
 - 7 Flynn, C., Lee, S-W., Peele, B., & Belcher, A., “Viruses as vehicles for growth, organization and assembly of materials” *Acta Materialia*, Volume 51, Issue 19, 25 November 2003, pp. 5867-5880.
 - 8 Araya, S., Zolotovskiy, E., & Gidekel, M., “Micro performances of bio fabrication”, in: *Physical Digitality. Proceedings of the 30th eCAADe Conference*, Achten, H., Pavlicek, J., Hulin, J., & Matejovska, D. (eds.), Prague: Czech Technical University, 2012, pp. 447-457.
 - 9 The term emergence is used to describe the acquired intelligence of a system comprised of non-intelligent elements. It is linked to cellular automata “*exhibiting complicated behavior analogous to that found with differential equations or iterated mappings*”. Wolfram, S., *Cellular Automata and Complexity*, Boulder: Westview Press, 2002, pp. 3-5.
 - 10 http://www.sial.rmit.edu.au/Projects/Aegis_Hyposurface.php (retrieved 16.10.2012)
 - 11 Based on Brooks’ work in 1986 it is possible to decompose complicated intelligent behavior into a large number of simpler behavior modules. Brooks, R. “A robust layered control system for a mobile robot” *IEEE Journal of Robotics and Automation*, Vol. 2, No. 1, March 1986, pp. 14–23.
 - 12 Addington, M., & Schodek, D., *Smart Materials and Technologies for the Architecture and Design Professions*, Oxford: Architectural Press/Elsevier, 2005, pp. 131-134.
 - 13 With the help of a computer program called AutoPLAN, developed by Kosta Terzidis in 2008, functionality in design can be achieved computationally through a thorough search of all possible solutions, based on the parameters initially set. Terzidis, K. “AutoPLAN: A stochastic generator of architectural plans from a building program” *FormZ Joint Study Journal*, 2007-08, pp. 84-87.

**(Re)thinking
the Seamless
and the Scaleless**

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**A Missing Scale,
a Shift of Culture
and a Quest for Agility**

General

The decisive changes that have occurred during the last decades in architecture and the way architects design the built world (or the world to be built) have affected the very vocabulary used to describe the spatial arrangements that gradually get established. A scaleless architecture has been an impossible notion, just like the ability to build seamlessly. What has happened, then, in the meantime, which has legitimized both notions and opened up the agenda of the architectural discussion? And most important, how did those notions apply to architecture and its design process?

Projects designed around the world suggest forms without seams; Architecture is becoming more responsive, dynamic, resembling natural systems, whether of biologic or vegetal origin; architectural structures incorporate radical features of open systems, re-generative mechanisms of constant replication and mutation. Separate units and components join with each other in seamless, organic ways and limits and borders are an essentially blurred, obsolete concept.

This paper initially suggests a bi-fold approach on the changes that are described above. The first approach is related to a geometric and formal reading of designed space that has to do with the scale of architectural elements and components. The second constitutes a cultural, stylistic approach related to human civilisations, contextual differentiations and the kind of architectural elements that are employed in the design process.

Geometric approach: a missing scale

A general and broad objective of this paper is to investigate advanced design techniques used by architects when designing space and the human-made environment in all its possible scales. Ground-breaking developments in digital technology during the late years have completely reshaped the design culture and redefined architecture's routines and methodologies.

The scale of things that architecture has been designing through the centuries had an obvious predisposition towards the human scale, an anthropomorphic approach that has been direct and graphical at times. The dependence on clear and solid geometry, the articulation of volumes and the final compositions have been all orchestrated and ultimately synced with the notion of clear, identifiable and solid shapes in the size and proportion of humans. This is not happening neither in larger nor in smaller scales in the natural world. Considering those scales, the microscopic environments of natural substances, as well as the greater world of nature, geology and dynamic movement systems, have all been characterized by an organic, fluid approach, genuinely and natively 'designed' by laws of evolution. The scientific advances in micro and macro scale, as well as the recent application on the human scale of architectural design provide the idea of a completely manipulative nature. This enables architecture to cancel any limitations concerning the possible range of design scales.

As mentioned previously, the rapid evolution of digital technology available to architects and the management of the morphogenetic process through digital modelling

techniques, encouraged architects to experiment on the structure and the morphological attributes of natural systems. These evolutions have facilitated the establishment of innovative, advanced design principles. We can now take advantage of their, unforeseen until today, capacity of integrating evolutionary computation, generative computation, physical environment modelling techniques, experimental strategies on the representation of three-dimensional space as well as prototype production methodologies. And this applies for the first time to the intermediate, regular scale of human dimensions.

Furthermore, the use of advanced computational means enabled the assignment of another, compelling goal to be achieved. This goal is related to the documentation and the instrumentalisation of natural processes of evolution and growth. Its obvious benefit is the enrichment of architectural modelling techniques, the clarifying of the essential features of emergence and the combining of these within a computational framework. The final outcome is the capability of developing generative design tools and the conception and ultimate production of complex and adaptive architectural forms, varying from microscopic scales to distant macroscopic observations, not excluding the in-between scale of human proportion. Advanced design technology has facilitated the application of these naturally advanced techniques in the missing, in-between scale of the 'human size'. This intermediate design scale range covering industrial design, architecture and urban design, can now be treated in a similar way, comparable to its larger and smaller analogues. This 'missing scale' is the vanguard field of current design research in architecture.

Seen from a broader spectrum, the attempt of a spatial expression or integration of similar advances and/or perceptions presupposes a wider association of architecture with digital technology sciences. An urgent investigation that needs to be implemented includes the examination of the potential revolutionary synergy between architecture, artificial intelligence, information theory, virtuality, cyberspace, climate studies, material science, bioengineering and nanotechnology. This covers a so-called 'digital pantheon', which is reshaping the world of architecture and the future paradigm of the man-made environments.

Cultural approach: a shift of culture

Innovative technology design research is already an established act and the use of digital tools can be considered as a given condition. Sometimes, though, the strict obeying to tools, features and software capabilities creates often myopic and short-sighted design outcomes. The kind of projects produced under this trend, are sometimes too involved with an obviously controllable micro scale, a long way down the design process. This is the reason why there is already a general attempt for a reaction against the establishment of a so-called 'digital rationalism', or even puritanism, when it comes to the form-finding techniques and space's formal characteristics. The denouncing of a so-called digital puritanism promotes a broader and more creative approach of innovative design tools and advanced methodologies. It encourages a more poetic hue in architectural design, a hue that reveals a more intuitive and narrative manipulation of space. Architecture produced under this trend, resorts to a more

narrative and plethoric documentation of an alternative, personal space, potentially evident and inhabitable. This space is perceived more through intuition than through the proper decoding of a respectable, digitally coded design language.

Following the shift in scale described in the previous section, could we start considering the possibility of a generic, intellectual shift of our design culture from a western one towards an oriental one? Western design has always been founded on a rational basis. This rationalism has been reflecting to Euclidian concepts about forms, grids and standard and linear approaches in core design decisions. It has also been reflected through the century old anthropomorphism of 'western' architecture. This comes as opposed to an 'oriental' design culture, rich in scaleless patterns and seamless architectural compositions, applied in a century-long design trend. This 'orientalism' of the design process is absolutely distanced from anthropomorphism, partly as a result of established cultural beliefs and an intense ability for narration, partly as a projection of a tighter relation to nature, its structures in all scales and ultimately its cause and effect. The use of computation in architectural design has offered an alternative, formally 'oriental' (in terms of its cultural attributes) approach to architectural matter. Apart from a radical liberation of the produced morphology, this shift has released some, so far taboo-considered, strategies such as ornament and decoration applied on architecture.

This kind of architecture can equip space with personality, eccentricity and character. Inevitably, as a result of the design mechanism going personal and the tools being freely available to anyone and substantially easy to use, there is an evident tendency for decoration. A whole new baroque feeling has emerged in advanced architectural design projects. Decoration and ornament returns sometimes in a massive scale, even though sometimes cleverly disguised under the identities of 'differentiation and adaptation schemes and variation studies'. Nevertheless it is plethoric and exuberant¹, rich in sensory and sensual stimuli. This new personal style is executed avoiding a graphic 'copy-paste' and any mimetic representation. On the contrary, what is suggested is an organic incorporation of decorative elements in a broader frame of morphological elaboration. Decorative complexity seems to be part of the newly defined attributes of architectural experiments and advanced, innovative design technologies.

Research by design

There is an already widespread design trend, mostly across academic environments and avant-garde design communities, which have already successfully addressed issues like the ones described previously. Three different design approaches will be presented here. Apart from their innovative architectonics, they seem to address a broader agenda covering most of the observations presented in the previous section and incorporating parameters related to scale, seamlessness and variation in advanced design.

a. Lapis Callidus²

A first speculation on these newly acclaimed qualities of design is the mobility through scales, thus the capacity to zoom inwards and outwards in the designed

structure. This is happening simultaneously and offers the designer the ability to enter a status of multiple observation of architectural matter. The project presented here is named after the Latin term 'Lapis Callidus', literally meaning 'smart stone', investigating the material expression of the archival 'recordings' of the continuous evolutionary and transformative processes in nature, directed to function as a communicating platform between information and the user.

One of the major repercussions of the rapid development in the fields of science and technology has been the renegotiation of the terms of nature and artifact, along with their relation to each other. In that context, the emergence of a new aesthetics, both in terms of materiality and spatial formations, relates to a set of natural elements, which have been formerly marginalized. Those aspects of nature, which are identified as 'subnatures'³, are initially considered as unreachable in terms of scale, either for the human user or for the material formations that constitute architecture.

The project speculates on the articulation of the, inherently complex, system of sulphur-crystalline structures through the coding and de-coding of the information, which is concentrated and exchanged on the digital world and the subsequent zooming in and out, and shifting of focal points. The potential architectural rhetoric that emerges from the engagement with this multi-sensory system is, unavoidably, connected with a simultaneous research on possible tooling techniques, which stimulate radical material transformations. Thus, the main challenge abiding is the development of an 'interface', which bridges the gap between the immaterial information and the material nature of archival recording and at the same time the gap between the mega-scale of the sulphur mines (Fig. 1) and the micro-scale of the encoding-decoding robotic mechanism (Fig. 2). The evolving architecture balances between the ubiquitous, invisible, digital world of information and the apparent, material expression of nature. A series of atmospheric, spatial episodes and their true, real-time physical documentation, offers a revisiting of material 'in detail' and 'by far', while at the same time maintaining a dialogue with immaterial architectonic qualities of space.

b. Texture Follows Form⁴

The second project, under the general title 'Texture Follows Form'⁵ has to do with design speculation on the creation of intermediate scales between the human and the surrounding reality. In other words, it investigates the architectural relation of the body with the environment in multiple scales. Natural procedures are being put under focus and the multiplication mechanisms of cellular structures are focal points of the research. Recursive subdivision is manipulated and used as the tectonic, architectural counterpart of cellular subdivision. Using three design studies, the 'nanosuit' (Fig. 3), the 'archimera' and the 'infraskin', the research aims to perform a series of zoom-ins and zoom-outs from the cosmologic to the microscopic and vice versa, through which a new archetypical architecture can emerge.

On a computer screen, one pixel adopts this mercurial nature always depending on certain conditions, which allow it to be translated and perceived in a variable mode. Thus, one pixel is an unknown distance. In a world where materialized parametrical



Fig. 1
Tsakiridis G., Kotsani E., 'Lapis Callidus', Archiving recording.

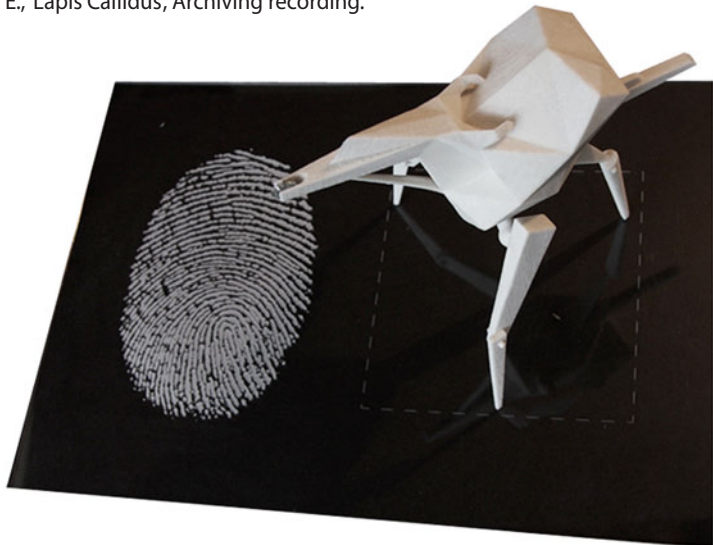


Fig. 2
Tsakiridis G., Kotsani E., 'Lapis Callidus', Robotic mechanism.



Fig. 3
Chlorokostas V., 'Texture Follows Form', Nanosuit.

models are beginning to merge with existing anthropometric data already experienced and empirically known, the need to seek a handful of distance begins to grow. As humans, we continuously touch objects, creating reference maps of textures, which support and complete our sense of vision of our surroundings.

What influences greatly this research is the idea that after an external phenomenon affects the body and before the birth of a conscious memory of that event, there is a multi-layered procedure, which is taking place. Brian Massumi specifically talks about a 'crowd of molecular or micro perceptions', each stratum of which 'has its own rules of content formation to feed its level-specific functioning, as well as unique forms of expression to transmit the generative impulse to other levels'⁶. Essentially, these 'micro-perceptions' stack in order to provide the brain with the necessary margin of unpredictability, on which the brain thrives and 'relays with other autonomies [...] from the cosmological to the microscopic, but also from the microscopic to the macroscopic'⁷.

Since recursive procedures can define this architectonic relation, one could speculate about the mutual recursive subdivision of the body and its environment. Subdivision of cells is a constant situation in the micro-scale of nature, so its tectonic counterpart



Fig. 4
Chlorokostas V., 'Texture Follows Form', InfraSkin.

could very well be recursive subdivision of geometries. This serves as a mediator in this dynamic relation of body against its environment (Fig. 4). It performs architectural mutations as a non-conscious reflex mechanism that addresses specific functionalities and conditions, and even interacts with real, cellular mutations in multiple scales.

*c. Bitter Vanitas*⁸

The speculation implemented within this third project has to do with attempts to explore the blurred boundaries of a world that emerges within the range of the human perception, without yet being clearly identifiable by the senses. It implies the hidden narratives of space and the inexhaustible potential of architectural matter.

The research project initiates with the study of real anatomical data from the 'Visible Human Project'⁹. A first objective is to produce a high-resolution digital three-dimensional model of the human head (Fig. 5). The segmentation of anatomical structures, semi-automatic contour extraction and smoothing the surface of the finished dissecting tumour through the design subdivision algorithm identified as 'discretized marching cubes' are the basic stages in the construction of the model. The virtual dive inside the digital three-dimensional model resulted in a distinct surveying, venturing on a different reading of the 'geography' and the subsequent topology of the human tissues. This offers an augmented potential in the field of architecture. A sui-generis, flexible design process is employed, attempting a simultaneous comprehending of the external form and internal constitution of a human corporeal element.



Fig. 5
Sagonas F., 'Bitter Vanitas', Human head model.



Fig. 6
Sagonas F., 'Bitter Vanitas', Immersive space.

The whole research project is related to questions trying to define a complex scientific entity, specified by individual questions about the theory of architecture, architectural design, advanced design capabilities, morphogenesis and space generating techniques. It incorporates elements of art, film and literature, as expressions of modern cultural production. As a result, it traces the still unclear reliefs of the architectural model of a world that emerges without yet being present, an immersive architecture entity (Fig. 6). It investigates the power of 'internal immersion' in a spatial condition, which manages to narrate through the undeniable immersive qualities of the suggested space.

Quest for agility

Summing up the basic argument, there is a promising shift of paradigm, which goes beyond issues of style, form and typology. The prominent architectural vision of western modernity, idolized through its transparent, neutral attitude about space has decisively begun to fade. Instead of being transparent, a new perception of architectural space is emerging, a space which is convoluted, complex, rich in meaning and confident enough to project its complex and intricate nature. The structures of this space hold an intrinsic, complex system of scales and there is no obvious methodology towards its physical or intellectual disentanglement.

The world seems to be within the horizon of systemic changes that will cascade through all the systems of nature and civilization. It is obvious that human structures and their networks will expand and develop, strongly coupled to the dynamic changes within they were situated. This has direct implications on the expanding urban environments. Architecture will be challenged to actively conceive and produce all new internal and external environmental arrangements. The built urban environment and its immediate surroundings are expected to become infused and converged¹⁰. Such a thought refers to an architecture beyond classic environmental entanglements that renders the thresholds between artificial and natural really blurred.

The notion of 'agility' appears as suitable to identify a series of notions and characteristics attached to the design mentality described above. A brief definition of the term 'agility' offers the explanation¹¹ of 'the ability to change the body's position efficiently, and requires the integration of isolated movement skills using a combination of balance, coordination, speed, reflexes, strength and endurance'. Agility here is not meant through the literal meaning of the term, even though these literal qualities hold certain validity, whatsoever. Agility, as a notion, codifies a rich set of qualities that architecture seems to venture to acquire, taking advantage of the design technology available. A big part of these notions can be documented in the three design projects presented above.

There is an evident need for the world of design to be able at the same time to cover ever-increasing territories of architecture's intellect and its spatial ambitions and to fit in minute gaps between its newly found scientific interdependencies. Thus, the issue of scale diffusion applies not only to structural geometry, but also to a requested intellectual calibre. The challenge of architecture is to achieve a level of physical

and intellectual agility; Physical so as to accommodate and digest the collapse of existing schemes of thinking and designing with scale and the articulation of volumes and shapes; Intellectual, so as to be able to enrich, though the delivery of the newly acclaimed knowledge, non-structural and non-engineering topics, thus to be able to hold 'illegitimate' talks about culture, context and architectural story-telling.

Notes

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**Integrative Iterations:
Designing Productive Processes
in Ecosystems of Information**

**Reflections on possibilities
attained through parametrized
design and L-Systems**

*We might call the form of an organism an event in space-time,
and not merely a configuration in space.*

D'Arcy Thompson

*The idea of the form implicitly contains also
the history of such a form.*

Hallé, Oldeman and Tomlinson

Introduction: Designs developing in informational ecosystems

We propose that nowadays, the development of designs in architecture and urban planning can be carried out similar to the growing of plants. This understanding arises from a shift in design away from objects towards processes that then produce objects or - in the case of urban structures - groups of objects. It is facilitated by the increasing capabilities and prevalence of digital design and production tools.

Comparable to the natural ecosystem - consisting of the natural environment - that plants grow in, designs can develop in an ecosystem where the natural environment is augmented by information coming from clients, consulting engineers, contractors etc. As plants digest (parts of) their ecosystem - soil, weather and sun conditions - to facilitate their growth, so designs can digest theirs to become more integrated with it. Through a large number of iterations, more and more information is integrated into an ever more consistent whole. Where plants grow in size, designs grow in complexity, consistency and relevance.

This understanding has a number of consequences in which various difficulties of traditional design processes are reduced or removed, oppositions are resolved, and new possibilities are opened up.

The role of digital design and production tools

Digital design tools enable designers to model their projects parametrically, simulate natural growth and selection processes and environmental conditions (gravity, weather) through L-Systems, evolutionary algorithms and environmental modeling software.

Parametrization does not interest us so much for its form-making strengths, but mainly for its integrative and responsive capabilities:

The parameters are ports of input through which information is fed into the design model. As parameters change, the model changes. Through the parameters changing with the environment, the model responds to it.

New parameters can be added, and existing ones extended in complexity and scope as the need arises. Through such a dynamic parametrisation - as opposed to a static one, where only the values of the parameters change, but not the parameters themselves - the degree of responsiveness of the model to its environment can be adjusted.

This means that projects are by definition context-sensitive.

Furthermore, parallel landscapes of possible solutions can be parsed by switching parameters on and off and thereby in turn strategically ignoring factors of uncertain importance. What to take into account and what not, and what in how far have always been questions in the design process that are as important as they are difficult. Parametrized models make this process much more explicit, structured and transparent.

Further extremely promising possibilities are opened up by simulating natural development processes through L-Systems. Originated by Aristid Lindenmayer, such systems establish a series of iterations in each of which parts of a structure are replaced according to a predefined set of rules. This sequence establishes precisely the process of continuous refinement that we are looking for.

Lastly, digital models can as a matter of course be shared with everybody involved and visualized at all times interactively, allowing for immediate and intuitive scrutiny, discussion and new ideas.

Consequences for contemporary and future design processes

We think that this understanding has a number of consequences in which various difficulties of traditional design processes are reduced or removed, oppositions are resolved, and new possibilities are opened up:

- i) Changing conditions (finance, politics, program, regulations, client requests, production and delivery capabilities) do not require repeated re-design but are integrated as a matter of course. All factors are, over time, modelled as parameters and their importance and influence on the project tested through alternative settings. If one or several factors change even after an architectonic proposal is considered appropriate by its designers, such change does not mean that the authors have to go back to the proverbial drawing board, but merely that the model has to re-computed with the new input data.
- ii) Constraints and requirements are not opposed but integrated; they do not restrict the design process but actually feed it. Projects are informed by their (conceptual and actual) environments instead of seeking to overcome them. This is the diametrical opposite of the traditional idea of planning and design where the world was shaped according to a preconceived idea, forcing the world to yield to ideas, having form follow function. Here, the world is seeded with ideas, and the form of the project emerges from the interaction of the two.
- iii) Evolving projects can act as sonar sensors probing the requirements, wishes, desires and secret dreams of clients as they react to the design proposals that are presented to them, only realizing their preferences when confronted with choice between alternatives. At the start of a design process, typically most preferences of clients are unstated and implicit. In order to develop a successful design it is important to make the implicit explicit. This mostly happens through a series of question and answer sessions between designers and clients. But it is also possible

to tease out clients' opinions by confronting them with proposals, not so much in order to have them accepted or rejected but to have them commented, allowing clients to form opinions about issues they had not been aware of. Humans are very good at making a choice between a number of options even if they do not know exactly what their reasoning is. Parametrized models almost by definition invite the creation of alternative proposals that then can be used to probe clients' minds like sonar devices.

- iv) As designs respond to and include more and more information, new unforeseen possibilities and solutions emerge, becoming recognizable as such only when they appear ('I'll know it when I see it.'). Johann Joachim Winckelmann, one of the founders of the discipline of art history in the 18th century, considered something to be 'good and beautiful, if it is what it has to be'. Such stringency is often only attained by solutions that could not have been foreseen but that as results of a design process are surprising when compared to early and naive preconceptions. We assert that the process of repeated inclusions of information described above fosters solutions of the stringency that Winckelmann strove for.
- v) Detailing and scale are not quantized into distinct sequential steps but occur on a multidirectional sliding scale: detail information is worked into the design as it becomes available, smaller scale parts feed back to larger scale structures and vice versa, detail may be removed and re-appear depending on the state of integration of the project. With pre-digital representation tools, design drawings had to be in fixed sizes and states. With digital tools, there are no limits to the scale into which one zooms in or out. Different parts of a drawing - or model - can easily be worked out into different levels of detail. Furthermore, design documents can contain their own history or versions of themselves that include different levels of detailing. Moreover, drawings and models can be linked to databases that contain further information that itself is changeable and developable. All in all, design documents are not unconnected representation of various parts of a project anymore, but gateways to a complex set of ever-evolving interconnected information that in its totality describes the project in its current and past states.
- vi) Contextuality is in-built and the a-contextuality of the international style - still an implicit paradigm with many architects and in many architecture schools - overcome. As projects digest information instead of confronting it, a degree of harmony with context is a necessary outcome. Projects are specific to situations like plants are specific to their place: specificity replaces generality. The modernist obsession with general solutions, buildings that were multiplied over the earth regardless of situational specificities, had at its root the economics of serial mass production: identical parts, the price of which shrunk with their number. And as for the buildings' components, as for the buildings. The advent of computer-controlled manufacturing has replaced such thinking and designing with customized mass production where all parts are neither equal or completely different but similar, like members of a family. Now variance can be mass produced, and specificity therefore become economical, and with it contextuality.

- vii) The borders between architecture, interior architecture, urban planning, regional planning and landscape architecture dissolve as the projects develop in scale and size according to the given information, necessities and possibilities and not according to preconceived categories. Digital models can dynamically grow or shrink in size and level of detail and can furthermore become processual instead of fixed into a specific state. Like digital animation suspends the traditional differentiation between painting and animation, digital design modeling discards the difference between planning disciplines that specialize in various scales and realization time.
- viii) Multi-disciplinary work becomes a matter of course as consulting engineers and other project partners input information from the very beginning to feed the development of the project, instead of coming onto the scene later as mere fixers. When the documents representing a project - be they one-dimensional texts, two-dimensional drawings, three-dimensional models, four-dimensional animations, multi-dimensional databases or combinations thereof - reside in the digital realm, they can be accessed and altered by several actors in parallel, making them multiply authored. Sharing and therefore also digesting information from different authors becomes not only easier but the norm. The traditional role of the architect as sole demiurge or godlike creator is superseded by a family of multiple parents, coming and going as necessity requires, jointly nurturing the development of the project like a team of gardeners caring for their plants.
- ix) Projects become structured, transparent, stringent and conclusive as the system of dependencies between requirements and solutions is laid open and the connection between input information and resulting design becomes apparent. Clients, users and the affected public are not confronted with apparently whimsical projects but presented understandable systems that integrate their needs and are open to respond to their desires. The monarchical model where more or less benevolent powers bestow buildings upon their users, deeming them unqualified and / or unworthy to have a say in their development is superseded by a democratic process of inclusion of different views and continuous development and negotiation of differing, sometimes opposing aspects. Projects are not developed despite differing user opinion or to educate the unknowing, but the knowledge and experiences of the future users becomes a necessary ingredient that seeds a projects' development.
- x) Time and space for intuitive play are opened up as the developing design systems allow for experimentation and easy testing of hypothesis. Men have always built tools to take over strenuous tasks, first for the body, later for the mind. Letters and books, for example, take over remembering and facilitate overview and browsing of information. In the same way, digital tools, used in the ways described above, can take over arduous and repetitive tasks of adjusting design projects to changing source data. The mental energy set free by this can now be used for more creative tasks that allow for play and intuition.

Conclusion

Digital tools like parametric modeling and L-Systems can help to have the situational circumstances of a design project take on the role that the terroir plays for a successful wine. Just as the growing vines feed upon the soil, a project can be nourished from its context and a specific product of strong character emerge.

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Fashionable Illusions

Claes Oldenburg and the human body

The relation of architecture to the other arts on the one hand and its uniqueness to combine them all in one piece is what forces Richard Williams to claim on his essay *'Architecture and Visual Culture'* that *'The architect is a special kind of artist who works in three dimensions, but unlike the sculptor, he – and this is still an overwhelmingly masculine profession – works to enclose space as well as simply making objects in space. It includes elements of the other arts, but it is superior to them because it is a synthesis of them all.'*¹ But when the human body appears as the main substance of the artwork (artistic, sculptural or architectural) this separation immediately collapses because it is not so important to focus on the separation of disciplines.

In a question of the poet and editor Paul Carroll to Claes Oldenburg about his intention to *'depict only objects instead of people as in such classical monuments'* the artist answered that *'I never show a human being or whole body; instead, I depict objects related to the person or part of the body. You could say the spectator himself supplies the whole body in question. Usually the object is something the spectator could wear, use, eat or relate his body to.'*² Even though, according to Barbara Haskell *'Oldenburg avoids the direct representation of the human figure because of the limitations it imposes'*³, in his proposed colossal monument *'London Knees 1966'* (Fig.1)⁴ Oldenburg objectified the female knees as a result of their fashionable exposure due to the miniskirt as it appeared in London during the 60s by using three methods *'the photograph, the cast, or what was already cast-the mannequin.'*⁵ Even though at this stage of his practice the proposed colossal monument is an un-built project, it shows the intentions of the artist to criticise the fashionable mass production of knee exhibitionism by transforming the female human body into an object just as the society transformed it through fashion.

Oldenburg does not make an exemption to gender because of his humoristic approach on the one hand and the criticism to human society on the other hand. *'The important thing about humor is that it opens people. They relax their guard and you can get your serious intentions across. If I were as didactic in my work as I really am, I would bore people to death. But, because I can put my message in a colourful, engaging form, my message isn't heavy.'*⁶ In 1969 (Fig. 2)⁷ he drew several colossal buildings in the form of binoculars (referencing the human pelvic region) entitled *'Buildings in the form of binoculars, pelvic region characters'* (Los Angeles, 1969). According to his description, that shows also his interest in architecture and the relation to the human body (opposing also the erotic element), *'Architecture, human structure and typography using the characters H, M and W. The whole pattern makes an F. The tiny strokes along the horizon line are people, indicating the scale. Smoke rises from the left 'tower', top center.'*⁸ The theme of binoculars as an architectural proposal appears also as a concept in 1984 for the *'Design for a Theatre Library for Venice in the Form of Binoculars and Knife Ship in Three Stages'* (Fig. 3)⁹ and as a constructed architectural component of the Chiat/Day Building designed by Frank O. Gehry (Fig. 4)¹⁰. According to Claes Oldenburg and Coosje van Bruggen, (the façade of the building was conceived with the use of three elements: the white ship like wall, the binoculars and the abstract tree forms), *'While looking at a model of the building façade, which was conceived in three parts, Frank had*

Fig. 1
 Claes Oldenburg 'London Knees
 1966'.

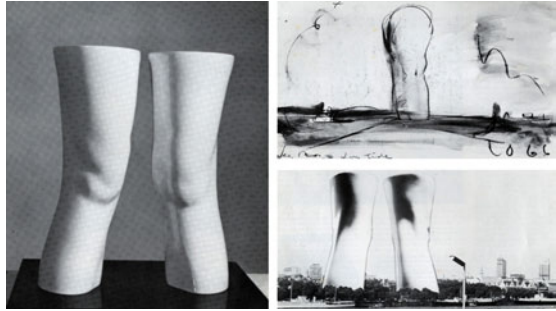


Fig. 2
 Claes Oldenburg 'Buildings' (1969).



Fig. 3
 Oldenburg & van Bruggen Design for a Theater
 Library in Venice (1984).



Fig. 4
 Binoculars, Chiat/Day Building (1991).

*decided that the central element needed something with more sculptural qualities. On an impulse he had taken the maquette that had been made for the theatre library on Coltello Island in the form of a pair of binoculars, which had stood on his desk, and put it in front of the building, where it seemed to function surprisingly well...The binoculars was conceived as a set of two identical rooms connected to a larger conference room in the main building...While the binoculars could be seen as part of the tradition of mimetic architecture in Los Angeles, we wanted to avoid the casual construction usually associated with such buildings; the binoculars was constructed in a precise technique using plaster over a metal frame to look as well as the architecture of which it was part. The colour, a deep blue grey, emphasizes the mass of the image and sets it off from the other parts of the façade. That the building stands not far from the ocean contributed to the appropriateness of the subject. For its occupants it seemed a fitting symbol of their visionary powers.'*¹¹

The dual meaning of anthropomorphism in architecture

In this dialogue between sculpture and architecture, and between built and un-built architecture, questions arise about the use of stereotypical figures and objects. What meaning underlies in the monumental and colossal practices in Oldenburg's sculpture with the use of the human body or parts of the human body? From architectural perspective what is the meaning of such (scaleless/seamless) 'objects' and how does such 'architecture' embody meaning in the relation between man and the mechanized world?

For the examination of the topic key references based on the concept of anthropomorphism in architecture will be the book of Scott Drake 'A Well-Composed Body, Anthropomorphism in Architecture' (2008), where the author examines a wide period of architectural theory since Vitruvius till contemporary practice with the examination of phenomenological and hermeneutical concepts. According to the author, 'To say that a building is like a body is to encourage forms of architecture that can be understood through the body, leading in turn to ways of understanding the body through architecture.'¹²

A second important reference will be Marco Frascari's 'Monsters of Architecture: Anthropomorphism in Architectural Theory' (1991). According to Frascari, 'Just as we think architecture with our bodies, we think our bodies through architecture. The rhetoric embodied in the above sentence displays a monstrous chiasm that implies a radical anthropomorphism in the concerns of architectural representation. This anthropomorphism can be understood as the ascription of human characteristics and attributes to buildings and edifices and it has long been part of architectural theory.'¹³ A further approach to the relation of human bodies and buildings was given by Joseph Rykwert in his book 'The Dancing Column' (1999). According to Joseph Rykwert, 'The condition for any person finding himself in the manmade world must therefore be that buildings should be like bodies in the first place and in the second, like whole worlds.' And continues, 'The condition, perhaps the only necessary condition under which architecture may be produced at all has always depended on that double metaphor, since architecture is the essential *parlar figurato* (the speaking figure) of building.'¹⁴ It is important therefore to rethink/re-criticise the scaleless and seamless in architecture. Because, the problem (or question,

criticism) it is not only in the constructional part of the building or as a result of such practice in the aesthetics of the final structure. And by this phrase the researcher's intention is to problematize on the relation of the human body's scaleless and seamless structure by means that such practical application could create a different kind of systemic con-structural thinking and practice. But from a theoretical perspective this only enables a practice, based on the same concept of the human; the innovation to a metaphorical 'static' catastasis. Does the scaleless and seamless create structures that imitate further the structures of nature, based on the innovation of the surface (the skin of the building)? On the one hand, as of the perspective of at least the exterior shape of the human body's structure or other natural systemic organisms, the whole structure is (or it seems to be appeared as) a synthesis of seamless and scaleless notation; on the other hand this practice in architecture forces the mind and architectural/artistic practice to a more mimetic praxis that is inevitable in human nature. The paradigm of sculpture as a scaleless and seamless synthesis in the artistic practice of the colossal sculptures as seen in Oldenburg's work for instance could be taken as a paradigm and guide for further thinking.

In his quite sentimental description regarding the 9/11 attack, in the essay *'Metaphors of Terror'* (2001), George Lacoff presents a metaphoric description of the falling towers. According to his description, *'The devastation that hit those towers that morning hit me. Buildings are metaphorically people. We see features—eyes, nose, and mouth—in their windows. I now realize that the image of the plane going into South Tower was for me an image of a bullet going through someone's head, the flame pouring from the other side blood spurting out. It was an assassination. The tower falling was a body falling. The bodies falling were me, relatives, friends.'*¹⁵ The 'sense of anthropomorphism', in this description, was within their capacity that included real humans; so the experience was not the exterior form but the meaning of use by the very human beings. Thus, a building is a medium of meaning, a medium of generated metaphors through its exterior and interior structure, through its purpose of function, through the conceptual thought of the creator, through the socio-political structures that was constructed and the socio-political structures that faces and will face through the period of time. As Mark L. Johnson indicates about the meaning in architecture and the relation to our own body as a result of such an action expressed by Lacoff, *'How could the destruction of these two buildings have changed America at such a deep level and so irreversibly? Part of the answer, I believe, lies in the way that human meaning is grounded in our embodiment and in the way that we make sense of our experience via metaphor and other imaginative devices. Architecture, as a form of symbolic interaction and expression, depends on these embodied dimensions of meaning and understanding. Consequently, an attack on a material structure- a building- can be an attack on our understanding of life at a very deep emotional level.'*¹⁶ Based on Lacoff's observation, Mark L. Johnson enforces the 'sense of anthropomorphic meaning' that lies beneath the surface of every architectural structure, and it could be related to the philosophical thinking of Jean-Paul Sartre as it was reviewed in the writings of Anthony Vidler in his text entitled *'Architecture Dismembered'* as part of his book *'The Architectural Uncanny, Essays in the Modern Unhomely.'* As Anthony Vidler writes about *'Sartre's proposition with regard to the body: the body is indicated firstly by an instrumental complex, and secondarily by a threat posed within this context: I live my body in danger as regards menacing machines as well as*

*manageable instruments. My body is everywhere: the bomb which destroys my house also damages my body insofar as the house was already an indication of my body [my emphasis]. This is why my body always extends across the tool which it utilizes: it is at the end of the cane on which I lean against the earth; it is at the end of the telescope which shows me the stars; it is on the chair, on the whole house; for it is my adaptation to these tools.*¹⁷ Previously in his text 'Architecture Dismembered' Anthony Vidler makes an observation that, 'The history of the bodily analogy in architecture, from Vitruvius to the present, might be described in one sense as the progressive distancing of the body from the building, a gradual extension of the anthropomorphic analogy into wider and wider domains leading insensibly but inexorably to the final "loss" of the body as an authoritative foundation for architecture. And he also identifies that, 'Three moments in this successive transformation of bodily projection seem especially important for contemporary theory: these might be described concisely as (1) the notion that a building is a body of some kind; (2) the idea that the building embodies states of the body or, more importantly, states of mind based on bodily sensation; and (3) the sense that the environment as a whole is endowed with bodily or at least organic characteristics.'¹⁸

Through the 'unconventional' architecture of Oldenburg, as seen in the case studies, the human body is being presented as the main medium or 'object' for the construction of architectural structures. This also indicates that the human body or 'a sense of anthropomorphism' appears in every aspect of architectural buildings as a meaning or depiction, not in a sense that only human characteristics are given to an architectural structure, rather the building itself projects the sense of the human body and it is in fact the human body. So in the categorisation of Vidler on the transformation of bodily projection it could be added a 4th moment or element that despite the intentions of the architect or '*the progressive distancing of the body from the building*' according to Vidler, there will always be 'a sense of anthropomorphism' in buildings (or a sense of the human body and the sense that the building is a human body). Based on these readings mentioned above and from philosophical and phenomenological perspective the researcher suggests that the human body or anthropomorphism in architecture also appears and depends each time on the relation of the building and the society and this can be proved in relation to the use or the evolution of the identity of the building through the historic continuum. If we take the example of the '*Twin Towers*' in New York the first impression before the collapse was that of '*the progressive distancing of the body from the building*' to use the words of Anthony Vidler; but after the tragedy, as Lacroff mentioned, the building transformed automatically into a human body or bodies applying to it a conceptual anthropomorphism.

In the sphere of architectural structures, it is the relation of the architectural practice and the poetics of the image (of the subject-object-human-building) that this case study analysed above from phenomenological perspective. Maybe, at this point, the approach of Venturi, Scott Brown and Izenour in their book '*Learning from Las Vegas*'¹⁹ as a postmodern analysis, would be interesting to use here; but more as a phenomenological approach of a semiological analysis in the retrospect and the experience of '*Learning from the Human Body*' (paraphrasing the title of the book '*Learning from Las Vegas*'). The '*Las Vegas Signs*' description of Venturi, Scott Brown and Izenour, it could be approached (paraphrasing the authors) by the phrase '*Human Body Signs*' of the anthropomorphism as seen in the work of Oldenburg in this case study for example (it

could be used also as a method of approach for the anthropomorphic buildings and the relation of the human body and architectural structures and in other case studies); by using the phrase *'Learning from the Human Body'* the researcher refers to the anthropomorphic and architectural structures of Claes Oldenburg as an example in the urban landscape of structured human-like bodies. As the authors wrote about the signs in Las Vegas *'Signs inflect toward the highway even more than buildings. The big sign – independent of the building and more or less sculptural or pictorial – inflects by its position, perpendicular to and at the edge of the highway, by its scale, and sometimes by its shape.'*²⁰ Therefore it would be interesting to add to this sentence of the authors before each of the word 'sign' the word 'human body (sign)' for a different approach and understanding of anthropomorphic architectural structures. Example:

'Human body signs inflect toward the highway even more than buildings. The big human body sign – independent of the building and more or less sculptural or pictorial – inflects by its position, perpendicular to and at the edge of the highway, by its scale, and sometimes by its shape.'

In order to adapt this method of approach and thinking (mentioned above) in architecture (or anthropomorphism in architecture) and the relation to the human body it has to be considered the comparative method of Venturi, Scott Brown and Izenour with their use of *'The Duck'* and *'The Decorated Shed'* (Fig. 5,6,7,8)²¹. In an attempt of the authors to identify their two main manifestations as they explain, *'We shall survey this contradiction in its two main manifestations:*

1. *Where the architectural systems of space, structure, and program are submerged and distorted by an overall symbolic form. This kind of building-becoming-sculpture we call the duck in honor of the duck-shaped drive-in, "The Long Island Duckling," illustrated in God's Own Junkyard by Peter Blake.*
2. *Where systems of space and structure are directly at the service of program, and ornament is applied independently of them. This will call the decorated shed.*

*The duck is the special building that is a symbol; the decorated shed is the conventional shelter that applies symbols.'*²²

Based on the example of Venturi, Scott Brown and Izenour and adapting it to anthropomorphism in architecture and the relation of the human body and architectural structures it could be said that two main categories appear in anthropomorphic architecture and buildings inspired by the comparative method of Venturi, Scott Brown and Izenour:

1. Firstly the visible/schematic (or 'open') anthropomorphism in architecture {(The Human Body (Duck)) (Fig. 9).
2. Secondly the conceptual (or 'closed') anthropomorphism in architecture {(The Human Body (Shade)) (Fig.10).

Or more in addition to the Human Body Signs (as mentioned above and the writings of Venturi, Scott Brown and Izenour paraphrasing *'Learning from Las Vegas'*) it could be said by using the phrase *'Learning from the Human Body'*, that two categories of Human Body Signs appear:

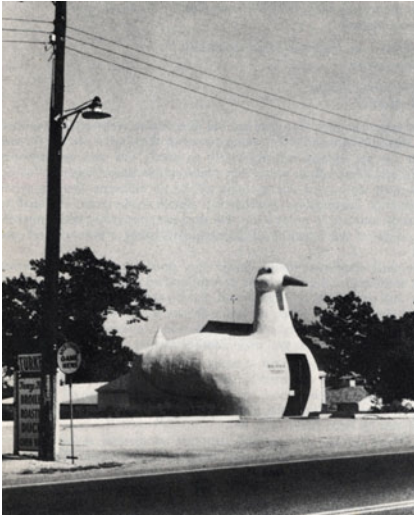


Fig. 5
 "Long Island Duckling" from God's Own Junkyard

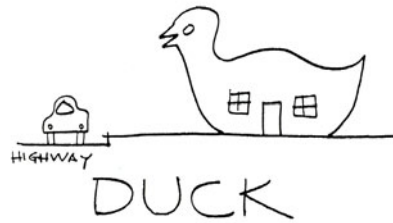


Fig. 6
 Duck.



Fig. 7
 Road scene from God's Own Junkyard.



Fig. 8
 Decorated Shed.

1. The Human Body Signs (the visible or 'open') (Fig. 9).
2. The Human Body Signs (conceptual or 'closed') (Fig. 10).

In conclusion there will always be 'a sense of anthropomorphism' in architectural structures because whenever man tries to 'enclose' his own body into a structure that he constructs, this notion inevitably relate his action to his own body. Therefore anthropomorphism will always be related to architecture whether it is visible or conceptual (whether the Human Body Signs are 'visible/open' or 'conceptual/closed' to man's perception of architecture).

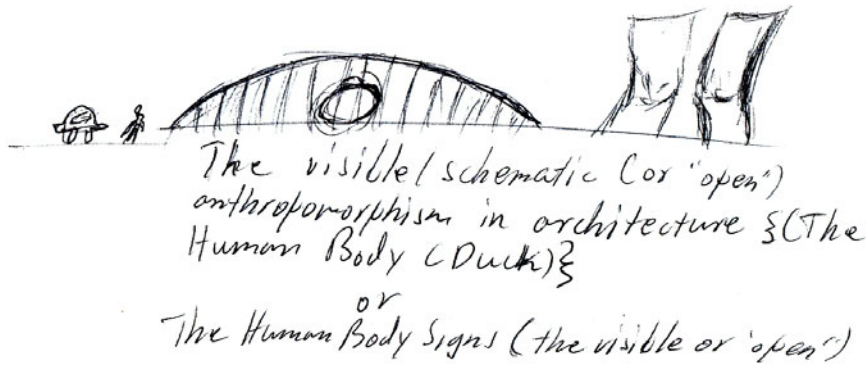


Fig. 9
 Charalampos Politakis (2012).

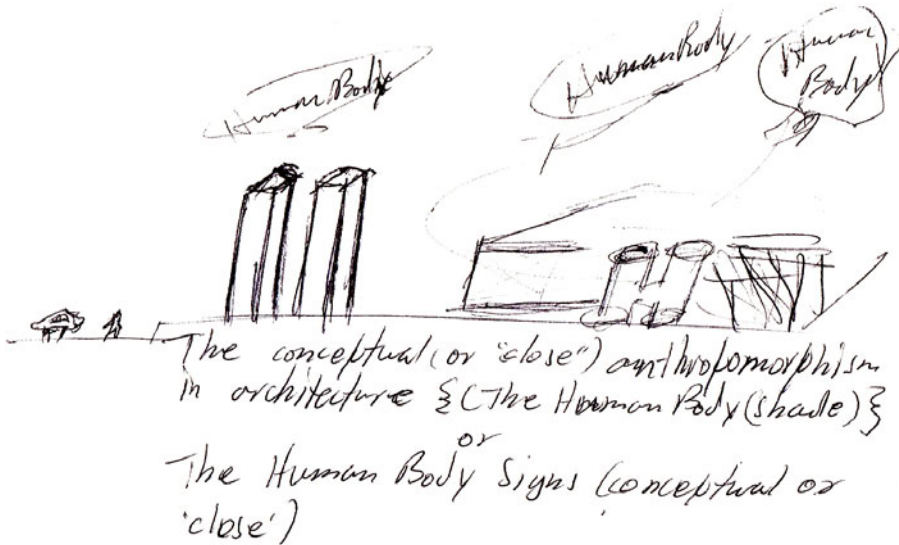


Fig. 10
 Charalampos Politakis (2012).

Notes

- 1 chapter> see Williams, R., "Architecture and Visual Culture", in: *Exploring Visual Culture: Definitions, Concepts, Contexts*, Rampley, M. (ed.), Edinburgh University Press, 2007, pp. 103-104.
- 2 book> see Oldenburg, C., *Claes Oldenburg Proposals for Monuments and Buildings 1965-1969*, Big Table Publishing Company, 1969.
- 3 book> see Haskell, B., *Claes Oldenburg: Object into Monument*, The Ward Ritchie Press, 1971.
- 4 *ibid.*, pp. 35-36.
- 5 *ibid.*, p. 35.
- 6 *ibid.*, p. 8.
- 7 book> see Oldenburg, C., *Notes in Hand*, Petersburg Press, 1971, p. 39.

- 8 book> see Oldenburg, C., *Notes in Hand*, Petersburg Press, 1971.
- 9 book> see Celant, G. (ed.), *Claes Oldenburg, Coosje van Bruggen*, Skira Editore S.p.A., 1999, p. 317.
- 10 *ibid.*, pp. 318-319.
- 11 *ibid.*, p. 316.
- 12 book> see Drake, S., *A Well-Composed Body-Anthropomorphism in Architecture*, VDM Verlag Dr Müller, 2008.
- 13 book> see Frascari, M., *Monsters of Architecture: Anthropomorphism in Architectural Theory*, Rowman & Littlefield Publishers, INC, 1991.
- 14 book> see Rykwert, J., *The Dancing Column: On Order in Architecture*, MIT Press, 1999.
- 15 website link> see Lacoff, G., *Metaphors of Terror*, 2001, accessed 19/10/2012, <<http://www.cse.buffalo.edu/~rapaport/575/F01/lakoff.on.terrorism.html>>.
- 16 paper in journal> see Johnson, M. L., "Architecture and the Embodied Mind" *OASE* issue 58, 2002, p. 76.
- 17 book> see Vidler, A., *The Architectural Uncanny: Essays in the Modern Unhomely*, MIT Press, 1992.
- 18 *ibid.*, p. 70.
- 19 book> see Venturi, R., Scott Brown, D., Izenour, S., *Learning from Las Vegas: the forgotten symbolism of architectural form*, MIT Press, 1977.
- 20 *ibid.*, p. 51.
- 21 *ibid.*, pp. 88-89.
- 22 *ibid.*, p. 87.

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Basic Entwinements

**Unassuming analogue inserts
in basic digital modelling [courses]**

*Everything we see hides another thing,
we always want to see what is hidden by what we see.*

René Magritte

The treachery of images

Before the possible assessment of any actual built (*arte*) fact, architectural manifestations and the ensuing discourse(s) mostly gravitate around its many, various representation(s). A vast *map-territory* relationship¹, functioning on many levels and scales encompassing both virtual and real.

Yet, as architectural representation(s) *per se*, they seemingly no longer are broadly recognizable as such, given the rapid spreading of state of the arts *renderings*², what might actually be seen is *representation(s)* on a multitude of layers, more multiverses than *arte-factuals*.

A different *treachery of image(s)*³, yet without any ambiguous by-lines, stating a revelatory, if ambiguous, thought-provoking negation⁴. The medium has, indeed, not only become the message, it has mutated into the embodiment of virtual space, perceived as factual.

With these – highly condensed – conditions meandering's in mind, a straight forward assignment was taken up, both as challenge and as possibility for further hindsight reflections.

Given were the pre-requisites of an already existing compulsory course in digital architectural modelling, into which, certain levels of analogue procedures were to be inculcated; With the added, keen directive, of adequate focussing on architectural *plan and section* awareness. Thus, a 3-week course in digital architectural modelling using *SketchUp 8* software for 1.st year students on the basis of own studio projects, was supplemented with 2 days of analogue exercises.

It was further wished, to give more perspective to the subject, to (possibly) include some form of theoretical lecture(s) into the tight frame.

From reification to construct(s)

With the very short two day timeframe given to implement these wishes in a 3 week course, a series of standardised MO's were developed, with special emphasis on very sparse, yet exceedingly analogue-*ish* paraphernalia: easily available white 80g. A4 paper and black *Filia* oil crayon(s).⁵

The choice of these unassuming tools was based on twofold reflections: their ubiquitousness would not be considered obtrusive in the standardised educational computer lab settings, while simultaneously enabling intensive analogue old-fashioned handcraft labour, with dust-free/water-free utensils in close vicinity to hard-disks and keyboards.

The available time was divided into precise activity slots, resulting in four roughly equal periods: two morning and two afternoon sessions; The first two sessions would include a short informal 20 minutes lecture with illustrations while the second day only included one lecture. Each session would host two short exercises to be repeated. A total of eight exercises could thus be run in the two day period.

While the exercises and the lectures had a large backbone of standardised material, each course would bring a certain amount of new conditions into the setting; as the analogue module was inserted into an already rolling digital course, and each 1.st year class would arrive with different architectural pre-requisites, certain crucial adjustments had to be performed ad-hoc.⁶

For most students this would be their first introduction to digital drafting, and their first ventures into digital architectural translations. Regardless of prior digital understanding(s)⁷, one of the most remarkable aspects of their (digital) endeavours was the unilateral cognition of the architectural translations as being “models” i.e. freely rotatable / freely scalable *artefacts*. While this condition at first glance might appear tautological, it would, at second glance, certainly appear to be much more of an oxymoron.

On further investigation(s), this prevalent *no-nonsense* cognition condition (considering “architecture” to be a controllable, rotatable, scalable artefact with *tweakable* qualities of plasticity) has two powerful underlying groundings at its base: the now universally recognised ease of *Bullet-time*, the *Matrix*-like view of ubiquitously rotatable objects in space⁸, and the even more obvious conclusion that “models” would be build by slices of (simulated) material (cardboard/wood, etc.); Both conditions would be fairly prevalent in most students approaches to SketchUp “modelling” efforts.

It clearly was obvious, that the actual architectural issues and primordial conditions where thus all together overlooked: the apparent WYSIWYG did not at all reveal (even in *wireframe* settings) conditions of space, spatiality, spatial interrelations or other architectural primordial conditions (light/dark, heavy/light).

Eventually those would, in later stages of the digital modelling course, become apparent, and thus subject to more conscious decision making.

Ultimately, the final renderings would develop into (“glossy”), fixed images of perspectival static, even if evolved into eventual stop-motion or faster frames, with the aforementioned “*The Third & Seventh*” on-line viral status as star(t) fixture for most eager and engaged first year architecture students.

What was clearly missing during the modelling(s), where abilities to consciously discern various crucial conditions of architectural space(s), capture these for further observation(s) in easily extemporaled and conceptualized form(s).

To make those conditions as visible and *tweakable* as the digital constructs, a form of architectural shorthand would be needed.

Rapid condition extracting [Tachi-graphé]

Enter Filia and paper: handicraft. This would produce an exact opposite of the ongoing digital constructions activities where each action has to be named and defined before its execution, introducing a clear shift in brain modality. The rapid paced exercises are indeed indebted to Betty Edwards seminal approaches to drawing⁹, yet performed (and then informed) in more oblique manners. The aims of the exercises are not to instil drawing skills per se, rather than introducing conceptual awareness on crucial architectural conditions via the simple and fast drawing exercises assessable results.

One obvious and apparent benefit after the first round of exercises is the very straightforward understanding of *gestalt* v/s object, and of the obvious possibilities to *re-view* and assess the seen in more oblique ways. Similarly, the initial frustrations with translating architectural issues into digital modelling steps – all in fact clearly verbalized, binary actions- are giving way to more playful aspects of realisation(s). *Seeing is forgetting the name of the thing one sees*¹⁰, in likewise *minimalistic* attempts to deemphasized the making of objects, focusing instead on an awareness of perceptual architectural phenomena, via the *Rapid condition extracting* drawings.

On the purely physiological side, the introduction of the exercises are clearly perceived as *different* after the first round: slow rotating and calibrating the digital model via (mostly) mouse/cursor analytical moves gives then way to a liberating change of pace via the insisting, repetitive circular crayon layerings on paper, attempting to create and even, simple gestalt layer.

Analogue Exercise(s)

For all exercises, there would be a short introduction and concise verbal information on MO's¹¹. The exercises would last for a maximum of 20 minutes, with an average of 15 minutes for each. The results would then be quickly collected for a short crit/presentation (10-15 minutes) with Q/A, conducted around A4 paper grid outlays directly on the lab floor. Each exercise would be repeated at least once.

The exercises would obliquely introduce, through the material produced, more focused sensitivities to the following architectural conditions /subjects: Volumetrics, tectonics, gestalt, interstitial space(s), body-space morphologies. Through further hybrid exercises and one particular surrealistic, *semi-automatic* frottage¹² exercise thought provoking and readily debatable material would thus be rapidly available. A complete list of the exercises and their variable MO's is included in the notes is following:

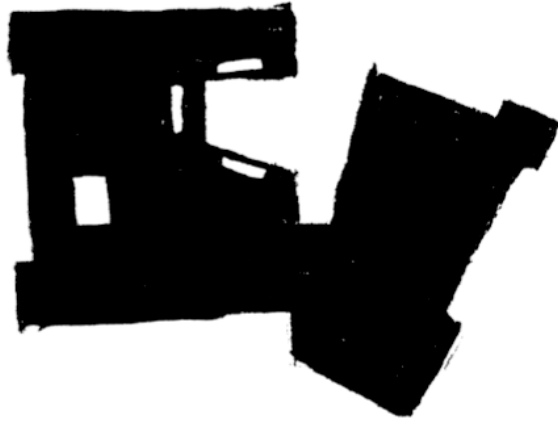
A – Volumetrics P/S

B – Volumetrics Light (N & A)

C – Tectonics

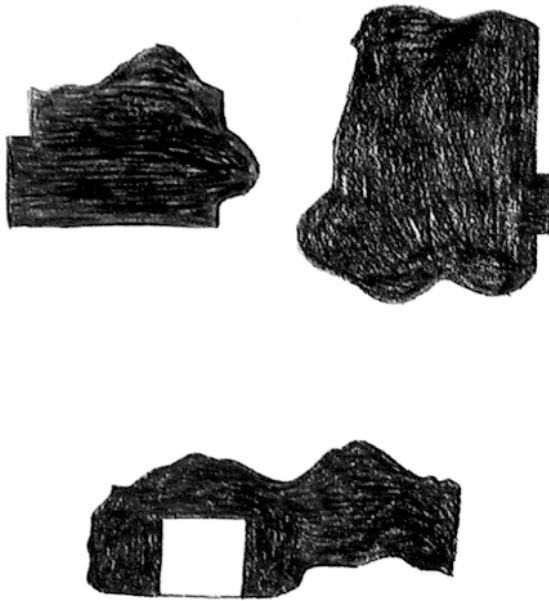
D – Gestalt

E – Interstitial space



This is not a plan

Fig. 1



These are not sections

Fig. 2

F – Body-Space morphologies

G – Frottage(s)

X – Hybrid(s)

Exercise I: PLAN / SECTION: Calibrate architectural object/project on SketchUp screen interface to standard split screen 4-view w/2D settings, axonometric; Extract plan and /or section of only interior air volume as 2D drawing on A4 paper; Edges defined by doors/windows; in case of openings, cut at exterior edge. Drawing surface to be evenly filled with black Filia crayon.

Exercise II: PLAN / SECTION/ LIGHT 1 with natural light: MO as exercise one, but with inclusion of light patterns on air volume and solids surfaces. Digital shadow rendering not allowed.

Exercise III: PLAN / SECTION / LIGHT 2 with artificial light: MO as exercise two, with inclusion of light pattern in air volume and solid surfaces by hypothetical artificial light source(s); Digital shadow rendering not allowed.

Exercise IV: TECTONICS: Calibration of digital model as exercise one, settings in wireframe. MO as exercise one, with clear identification of tectonic architectural elements:

Successful examples of Exercises I – IV taken as basis for “homework” for next day: Scan or photocopy, reprint 100% as inverted.

Exercise V: GESTALT: Calibration of digital model as exercise IV, settings in wireframe; MO as exercise I with identification of potential “gestalt” figures following either given architectural patterns and/or other identified patterns. Proceed in either case primarily by intuition.

Exercise VI: INTERSTITIAL SPACE: Calibration of digital model as exercise IV, settings in wireframe; MO as exercise I with identification of actual or presumed interstitial spaces; render figures following either given architectural patterns and/or other identified patterns. Proceed in either case primarily by intuition.

Exercise VII: BODY SPACE MORPHOLOGY: Calibration of digital model as exercise IV; alternate with perspective settings; settings in wireframe; MO as exercise I with identification of presumed movement patterns. Patterns/notations/mappings to primarily follow architectural settings; Proceed in either case primarily by intuition, yet follow architectural settings closely.

Exercise VIII: FROTTAGE(s): On the basis of produced results from exercises I – VII elaborate cut-out of the patterns /gestalt form. Use both positive and negative paper cut-out as basis for simple frottages. Exercise usually repeated 3 times for satisfying outcome(s).

Exercise O: HYBRID(S) All exercises could be tweaked according to the various architectural states of the students projects, thus giving the opportunity of having a more

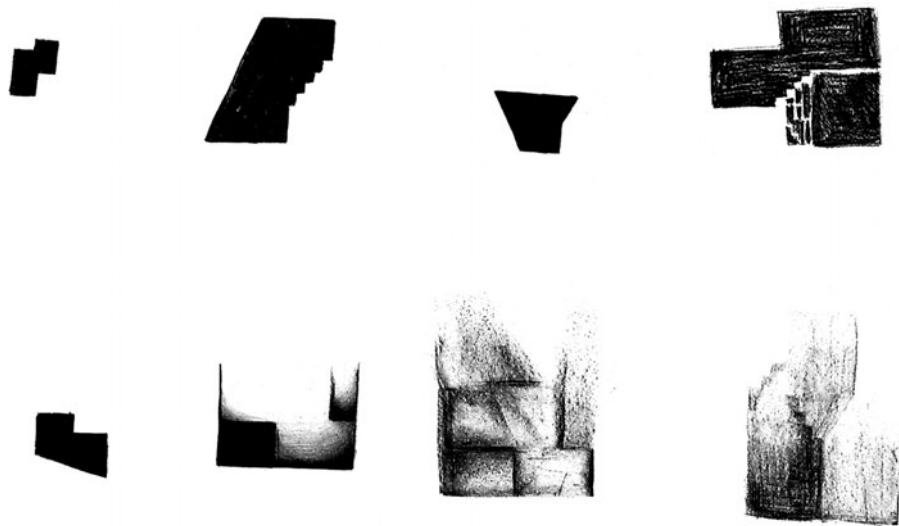


Fig. 3
Sample of exercise II + III.

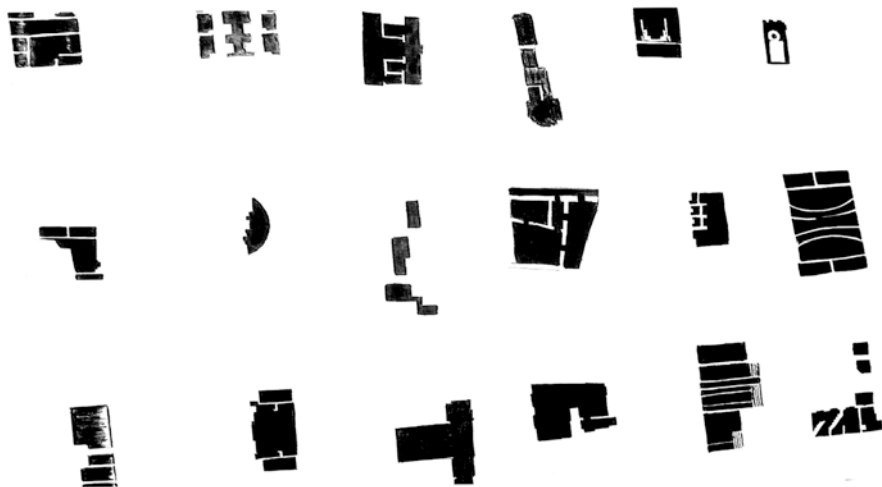


Fig. 4
Sample of exercise I and II.

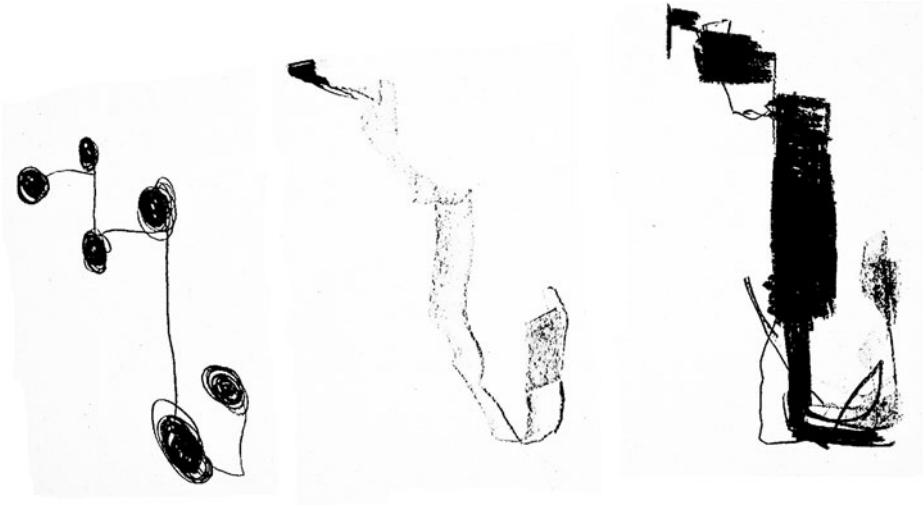


Fig. 5
Sample of exercise VII.

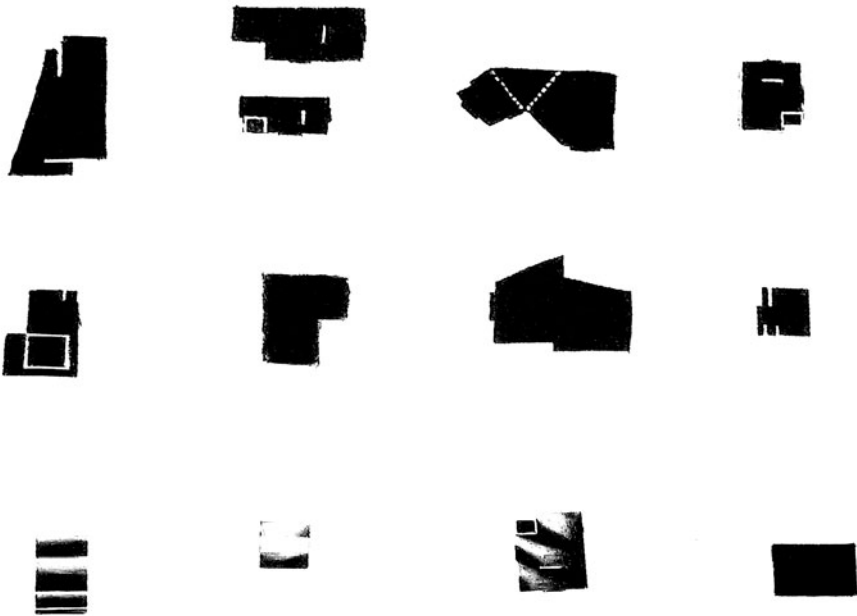


Fig. 6
Sample of exercise I, II and III.



Fig. 7
Sample of exercise outlay.



Fig. 8
Seamlesscaleless situation.

close dialogue with ongoing architectural design work. Tweak examples: combination of exercises i.e. II and VII, IV and VIII, and use of VIII for elaboration(s) of landscaping / site plans / interiors, etc.

Complement

As the production of the exercise's various tasks would very quickly yield relatively large amounts of both qualitative and highly debatable material¹³, the informal lecture(s) would act as complementary, intellectual *sorbets*, inserted with effective, yet *casual care*.

The lecture(s) presented as PP slides would informally circle around more general topics of architectural (re)presentations with examples from antiquity to present day, yet without forming any stringent, historical course. Certain examples would be highlighted, presented in quiz form to the audience, to assess the class's average level of basic architectural knowledge¹⁴ and drafting terminology.

As the lectures were designed to act as informal catalyst for interactive conversations, the presented examples acted simultaneously as both generic and more specific architectural lineaments. After the informal determined level understanding of the class after the first lecture's quizzes, slides would be re-adjusted for the next lecture.

While introducing the more classic issues of architectural rendering(s) for the students, other, more contemporary examples of recent scaleless *rotation conditions* were inserted. These inserts would usually consist of easily available short on-line videos. The Eames's *The Power of Ten*¹⁵ would act as cornerstone to the opening of this discrete parallel discourse. Other highlights would include *The Campanile Movie* and its subsequent Matrix Bullet-Time sequence¹⁶, including, if time would permit, the subsequent *Shrek* and other filmic parodies.

What would be considered as puerile digression(s) is actually firmly grounded in reality. The ubiquitous ways by which serious surfing with Google Earth is nowadays practiced with childish ease, combined with the investigative virtual rides globally via Google Street View, would presupposes a well developed cognitive awareness of satellites and drone's perspectival shift.

Actually, this is not necessarily the case.

Court-circuits or new tracés regulateurs

Memory is, indeed, short: Google Earth was introduced in 2005, Google Street View in 2007. The European mappings are even more recent, depending on location. The astonishing ease, and particularly the somewhat unsettling *un-impressiveness* with which these tools are integrated into the (global) quotidian, is mind-boggling. At first(!) The novel, ensuing body-space morphologies, while blurring the fault-lines and boundaries of virtual and real, pre-suppose a wholly different change of perspective paradigm: the irreversible detachment of the eye from the body, inducing a multifaceted, simultaneous multi-verse.

The (scaleless) free rotation of objects has mutated to include the (scaleless) free rotation of the ocular, body-centered condition. To include this change of paradigm as complementary cognitive information further on-line video snippets were included (when time would permit it) to the informal lectures. Joe Kittinger's jump would be contrasted with Felix Baumgartner's preparations, Apollo 8's first filmic evidence of planet Earth appearance behind the moon, amateur's cheap but effective balloon expeditions to space (and the many parodies thereof), Jeb Corliss's *Grinding the Crac*, and the many other *Go-Pro*¹⁷ manufactured views that were impossible just a decade ago¹⁸.

With the rapid deployment and miniaturisation of flying drones and other UAV enabling even more stunning imagery¹⁹, the finalisation of the body-less ocularity and its shift into the realms of the ubiquitous quotidian has already happened.

Architecturally, the scaleless rotation from seemingly unattainable viewpoints is already in full deployment²⁰, while more sophisticated rotation(s)²¹ pave the way for completely novel ways of future building.

'Pataphysics

The somehow extreme agglomeration of intensely focused manual exercises, general pictorial lecture(s) with quiz inlays, and video inserts, might, on first glance, appear to be a somewhat up geared endeavour. Compared with classical drawing/drafting classes, and the usual step-by-step didactic inoculations of hard and software to amalgamate architectural design studio production.

The actual didactics accompanying the *Rapid condition extracting* exercises are a indeed a form of ludic thrust, balancing already obsolete representation techniques in an attempt to recalibrate radically rescued analogue practices, tweaking them, to cognitively fit new and constantly changing digital conditions. All the while the digital MO are themselves becoming obsolete, with the ongoing perfection of 3D printers and advanced digital translation software.

The short two-day course module could be viewed as a joyful 'pataphysical²² insert, stirring a rather technocratic course with thought-provoking re-introductions and calibrations. Alfred Jarry's "*Science of imaginary solutions, which symbolically attributes the properties of objects, described by their virtuality, to their lineaments*" is much less Dada than first anticipated.

In their seminal treatise on architectural representation Alberto Perez-Gomez and Louise Pelletier state that:

*"If we persevere in our obsessive search for a scientific theory of architecture, we may finally stumble upon a model that is truly appropriate for the architect's search for form: ...Jarry's "science" of 'pataphysics. As opposed to traditional science, pataphysics celebrates the sheer unlikeliness of pure theory, noting the remarkable improbability of the circumstance that we live on Earth and are able to see the stars. Indeed, pataphysics remind us that the conditions necessary for life do not exclude those necessary for vision or vice-versa, an exceptional point, often overlooked..."*²³

Coda (seamlesscaleless)

In the frantic pace of a first year architectural curriculum, a two-day modular insert of analogue drawing in a longer digital modelling foundation course might not be evaluated to any status of *hinge*. Nevertheless, it has been the constant trickling of positive informal, ad-hoc feedback from participating students that fuelled the recapitulation of a now defunct course supplement.

The cognitive element of scalelessness had been introduced with relative ease via the many puzzle-like analogue realisations that continued emanating from the simple *Filia* exercises. Apparently, these simple *skills* were sufficiently inoculated to surface when needed to bridge the language gap of intuitive intentions meeting digital translations in architectural design situations.

The wishes to creating bonded amalgams between analogue and digital situations were translated into more *quirky* situations of constant overlay(s), generating a buzz-like readiness to change media when needed. If conditions of *seamlessness* and *scalelessness* would be considered as hybrid life-forms, with inherent capabilities for situation-compatible adaptability, much is gained.

In the actual global habitat of rapidly changing technological shifts, the momentary insert and training of small analogue *instamatics*, frozen cognitive flash-backs in creative architectural/design education will first show its real value in some years, after graduation and with establishment of next generation's idiosyncratic integrities.

Until then: Il faut cultiver son jardin.

Notes

- 1 "The map–territory relation describes the relationship between an object and the presentation of that object, as in the relation between a geographical territory and a map of it. Polish-American scientist and philosopher Alfred Korzybski remarked that "the map is not the territory", encapsulating his view that an abstraction derived from something, or a reaction to it, is not the thing itself. Korzybski held that many people do confuse maps with territories, i.e. confuse models of reality with reality itself." *Wikipedia's definition of "map-territory relation" term as of September 2012.*
- 2 One absolutely jaw-dropping CG rendering that surfaced in 2011, is Spanish CG world artist Alex Roman's seminal, incredibly photorealistic "*The Third & Seventh*" video. In it, he manages to reconstruct the interiors (and all exteriors too) of both Louis Khan's Exeter library and the Dacca parliament. Most mindboggling is the fact that *all* arte-facts depicted in the video are computer generated. To say the least of the amazing controls of architectural light ("natural" and artificial- both digital virtualities. Video URL > <http://vimeo.com/7809605>.
- 3 *The Treachery of Images* (*La trahison des images*, 1928–29, sometimes translated as *The Treason of Images*) is a seminal painting by René Magritte. The picture shows a pipe. Below it, Magritte painted, "*Ceci n'est pas une pipe*", French for "This is not a pipe."
- 4 In Michel Foucault's essay from 1968 titled *Ceci n'est pas une pipe* inspired by Magritte's painting, Foucault focuses on the unusual effect, what he termed its "strangeness" created by the drawing's highly realistic depiction of a pipe and the legend below it, stating, "This is not a pipe." Foucault argued that the incongruity between the pipe and its legend illustrated his

position, that “[neither words nor the visible] can be reduced to the other’s terms: it is in vain that we say what we see; what we see never resides in what we say. And it is in vain that we attempt to show, by the use of images, metaphors, or similes, what we are saying...”. Thus, the drawing strips us of the certainty that the pipe is a pipe, and and “inaugurates a play of transferences that run, proliferate, propagate, and correspond within the layout of the painting, affirming and representing nothing.”

“inaugurates a play of transferences that run, proliferate, propagate, and correspond within the layout of the painting, affirming and representing nothing.”

Foucault, Michel. *This Is Not a Pipe*. Tr. James Harkness. Berkeley: University of California Press, 1983.

5 *Filia* oil Crayons have a special history: invented in collaboration by a Danish engineer and a steel manufacturing plant in 1952, the crayons have been ubiquitous staple in Danish kindergartens and primary schools. While remembered with fondness by most Danes, the crayons possible use as serious tool by adult professionals was certainly not an established practice. (With the re-introduction of *Filia* crayons in various architectural drafting courses, younger Danish architects would now deftly use it as a conceptual sketching tool, surpassing other traditional analogue tools.)

6 Ten (10), later nine(9) classes of first year students from different departments would pass through the compulsory foundation course; The primary objective was the introduction and subsequent handling of architectural digital modelling techniques via SketshUp8 software; The SketchUp models would later in the course be rendered by various rendering software applications. To each course, classes would bring already (more or less) elaborated design studio project results; Almost all classes would bring very different architectural material (ranging from intricate conceptual architectural forms/shapes to reduced one-room shelters via smaller, more regular projects with some sort of in-built programmatic functionalities as stepping stone for digital modelling translations. The two-day analogue module was usually inserted after a week/10 days into the digital course.

7 While only one department had, early on, given their students a thorough intro and handling of Autodesk 3DStudio MAX, this was the case for all other classes.

8 *Bullet time* (also known as frozen time, the big freeze, dead time, flow motion, or time slice) is a special and visual effect that refers to a digitally enhanced simulation of variable-speed (i.e. slow motion, time-lapse, etc.) The term “bullet time” is a registered trademark of Warner Bros., who first used it in March 2005, in connection with the video game *The Matrix Online*. The term had previously been used in the promotion of the 1999 film *The Matrix*. (*Wikipedia entry, sept. 2012*)

Actually the Campanile at the University of California, Berkeley, was the first architectural object subjected to virtual camera moves by Paul Debevec in his ground-braking “Campanile movie” (1997). Technology and know-how then made their successful transfer to Hollywood via Debevec’s PhD Student George Borshukov. Borshukov was hired by The Martix’s visual effects team to implement the “bullet-time” effects. Links:

“The Campanile Movie”: <http://www.debevec.org/Movies/debevec-campanile.mov>

Relevant cross-over facts at: <http://www.debevec.org/Campanile/>

It is the ensuing “bullet-time” effect, re-used in countless films and other moving visuals since that established the ubiquity of the form-in-space cognition.

3D Tetris appeared in the mid-90’s, evolving into equally ubiquitous conditions in most AV or filmic settings thereafter.

9 Betty Edwards, American art teacher and author, is best known for her 1979 book, *Drawing on the Right Side of the Brain*. Edwards’s method of drawing and teaching was revolutionary when she published it in 1979. Underlying the method is the notion that the brain has two ways of perceiving and processing reality — one verbal and analytic, the other visual and perceptual.

Edwards' method advocates suppressing the former in favour of the latter. It focuses on disregarding preconceived notions of what the drawn object should look like, and on individually "seeing" edges or lines, spaces, relationships, and lights and shadows, later combining them and seeing them as a whole, or gestalt.

Edwards's early work was based in part on her understanding of neuroscience, especially the cerebral hemisphere research suggesting that the two hemispheres of the brain have different functions. She spoke of verbal/analytic processing as taking place in the brain's left hemisphere, and visual/perceptual processing as taking place in the right. When later research showed that the locus of these activities is much less clear cut, she began calling the two modes "left mode" and "right mode", respectively."

Edwards, Betty, *The New Drawing on the Right Side of the Brain*, Tarcher/Putnam, 1999

- 10 Weschler, Lawrence: *Seeing Is Forgetting the Name of the Thing One Sees: Over Thirty Years of Conversations with Robert Irwin*, Berkeley, University of California Press, 2008.
- 11 Information, instructions and concise MO's were not given in writing, establishing from the start of each exercise, a playful climate of interactive intensity, prioritizing intuitive action over "analytical" broodings. Students were welcome to ask short, specific questions while working, to emphasise more direct approaches to the actions.
- 12 Frottage (from French *frotter*, "to rub") is a surrealist and "automatic" method of creative production developed by artist Max Ernst.
- 13 As a class would average 25 students, each exercise would generate a minimum of 2-3 A4 per student. A quick crit/outlay of material from each exercise would cover a surface of 6-9 m².
- 14 While some illustrations would be of more general character, specific examples of architectural drawings would serve as basis for interactive quizzes: a simple facade drawing of Villa Godi by Palladio, a plan and a section of Borromini's San Carlo alle Quattro Fontane, a plan/section of Vila Rotunda by Palladio, a site plan and detailed plan of Villa Marea by Aalto, plans and sections of Corbusier's Weber Pavilion. To assess knowledge of drafting terminology, various examples of axonometric representations were included.
- 15 Charles and Ray Eames's seminal short film's (second version from 1977) original title is: *Powers of Ten: A Film Dealing with the Relative Size of Things in the Universe and the Effect of Adding Another Zero*. The actual Best version available at YouTube > <http://yt.cl.nr/0fKBhvDjuy0>
- 16 Matrix's Bullet-Time sequence: Youtube clip > <http://yt.cl.nr/WhxbYTMNMxo>
Bullet time in chroma > Youtube clip: > <http://yt.cl.nr/jrd8kgWlku4>
What is bullet-time > Youtube clip> http://yt.cl.nr/_KtghA0rkDY
Campanile Movie > <http://www.debevec.org/Movies/debevec-campanile.mov>
- 17 Go-Pro is a miniature, waterproof wearable High Definition video camera, that since it's appearance in 2007 have enabled stunning new moving images from most unusual viewpoints.
- 18 Joe Kittinger > http://yt.cl.nr/Qw8OJJQ_hgk
Felix Baumgartner 96,000 ft Test Jump 2012 > http://yt.cl.nr/s_SzUnkYcR4
Apollo 8 Christmas > <http://yt.cl.nr/skSbdBo15vQ>
Jeb Corliss " Grinding The Crack" > <http://yt.cl.nr/TWfph3iNC-k>
Space Balloon - Stratosphere Spacecraft Launched From Newburgh, NY > <http://yt.cl.nr/y6ZMscMp8UM>
- 19 Drones and UAV's > http://en.wikipedia.org/wiki/Unmanned_aerial_vehicle
Nano Humming bird > http://en.wikipedia.org/wiki/Nano_Hummingbird
AR drone > <http://ardrone.parrot.com/parrot-ar-drone/select-site>
- 20 Extraordinary urban amateur UAV videos from all over the globe > <http://team-blacksheep.com/videos>.

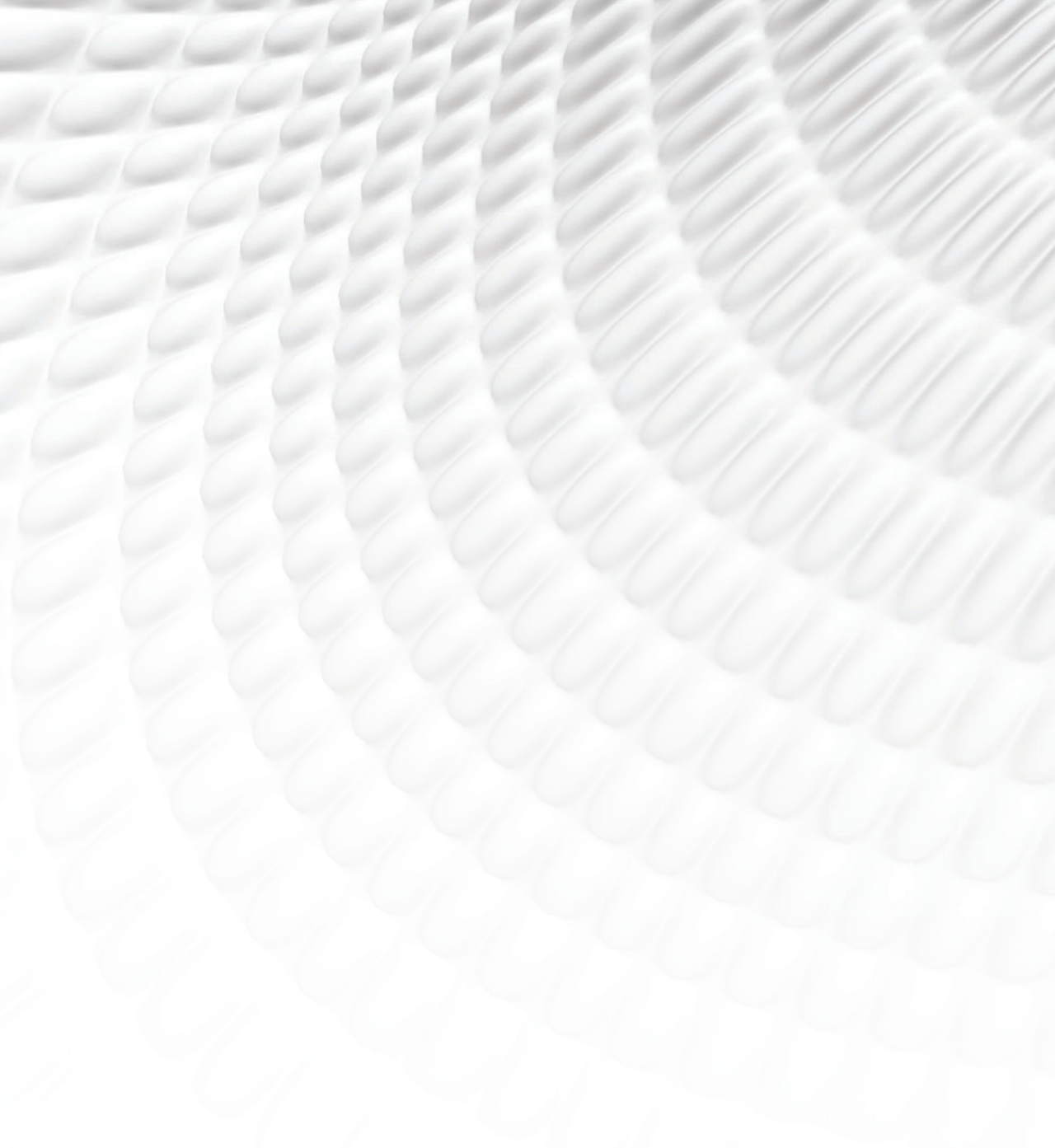
21 Flight Assembled Architecture > <http://yt.cl.nr/JnkMyfQ5YfY>

ETH Zurich roboticist Raffaello D'Andrea and architects Fabio Gramazio and Matthias Kohler teamed up to have the quad-rotors build a 1:100 scale model of a tower envisioned by the architects. This resulted in the first art installation to be built by flying robots: a 6 m tall tower made out of Styrofoam blocks. (2011).

22 A recent MIT publication is a thorough documentation of 'Pataphysics >'

Hugill, Andrew: *'Pataphysics, A useless guide*. MIT Press, Cambridge, Mass. 2012.

23 Perez_gomez, Alberto: *Architectural representation and the perspective hinge*, MIT Press, Cambridge Mass, 2000, p. 296.



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