Caterina Tiazzoldi

Measurable and Non Measurable in Architecture
3 case studies of the Non Linear Solutions Unit

Caterina Tiazzoldi
Assistant Professor, PhD
GSAPP, Columbia University
caterina@tiazzoldi.org
DIPRADI Politecnico di Torino
tiazzoldi@nuovaordentra.org

Caterina Tiazzoldi

Measurable and Non Measurable in Architecture
3 case studies of the Non Linear Solutions Unit

Abstract

In the last fifteen years architecture's frequent use of complex digital design instruments, such as algorithms, dynamic relationships, parametric systems, mapping, morphogenesis, cellular automata and bifurcation with broken symmetry, clearly shows how contemporary thinking in mathematics and physical sciences has changed the way we think about design. The incorporation of dynamics, n*onlinear s*ystems, chaos theory, emergent properties, resilience, etc., has altered our perception of the life of today's cities.

The pilot model, Applied Responsive Devices (ARD), is a methodological approach formulated to question how the change of paradigm affects the decision-making of designers. ARD has been developed within the context of the Nonlinear Solutions Unit (NSU) at Columbia University's Architecture School. The purpose of NSU is to analyse the impact of the change of paradigm in architectural research and to consolidate research in the field of complex systems in architecture. It questions how to enhance the organisation and transfer of architectural knowledge by activating a strong interaction between analogue and digital modelling. ARD's role is to embed sets of constraints within the modelling process that affect the decision-making of the designer. The innovation includes the way in which quantitative and qualitative parameters (i.e. social, physical, sensorial, cultural and economic) are aggregated in order to emphasise the concept of formal adaptation.

Some architectural problems can be managed with a classifier system consisting of a set of rules, each of which performs particular actions every time its conditions are satisfied by a specific informational attribute. By taking into account the experimentations developed in the field of cognitive sciences (Holland, 1992), the methods contained in this proposal investigate the existing relationships between the perception of a specific reality and its translation into a set of elements that can be manipulated through computerised models.

1. Architectural codes and the definition
of the threshold between the *Measurable* and the *Non-Measurable*

The idea of architectural codes operates on a double level.

The first, acting within the field of the *Non-Measurable* or metaphysical, aims to improve our understanding of the universe. The second, by operating in the context of the *Measurable*, has the purpose of improving the technical level and accuracy of the architectural tools; it focuses on application to concrete cases as regards achievement, production and project management.

In a first phase architects' interest is focused mainly on the *non-measurable* dimension of the code. They query the relationship existing between architecture and its possible translation into symbolic language: the relation existing between architecture and pure mathematics.   The chance to express and understand a specific reality through the formulation of mathematical expressions representing its internal organisation questions the essence of the relation existing between a specific reality and the reading we do of it.

During the nineties, architects' use of the code was mostly based on its direct transposition to the architecture of tools developed in other scientific fields. The use of instruments deriving from computer science such as cellular automata, or from botany such as L-system and other rewriting techniques, algorithms borrowed from genetics or systems devices such as the complex adaptive systems developed within the field of cognitive sciences, provided architects with new instruments supporting formal and conceptual investigation. The transition from the classical paradigm to the science of complexity, engendered a new vision of architectural research. It engendered an epistemological change in architectural approach.

 In effect, in a complex-structured city in which the interactions among parts intensify, in which the number of decision-makers and cultural scenarios overlap, interconnect, and sometimes collide, in which the temporal dimensions of the citizens are dissimilar, in which local and global, physical and virtual dimensions co-exist, it is necessary to respond with new typologies, new complex urban organisms and new research tools. Architects have to face different realities, in which building typologies and space-using modalities are continuously coming under question. It becomes crucial to define a set of complex adaptive tools which are able suitably to manage these complexities within the system.[1]
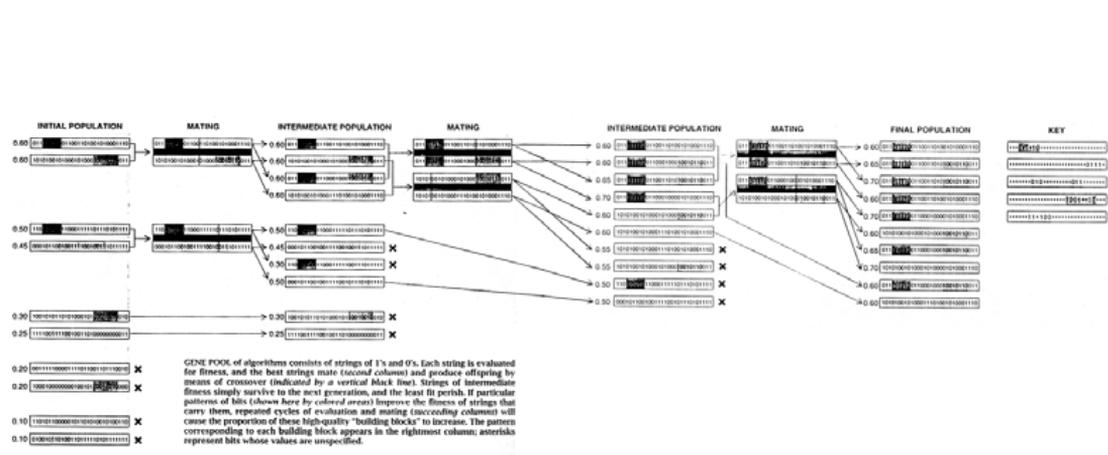

Figure 1

Example of genetic algorithm

Information available from: url:http://www.econ.iastate.edu/tesfatsi/holland.GAIntro.htm

The introduction of advanced digital tools deriving from the science of complexity promised to be a strong support to the architectural research. The adoption of tools developed in other scientific fields allowed architects to have a new vision of traditional architectural problems. The use of algorithms and codes derived from complexity science allowed architects to discover forms of order and hidden organisations that couldn't be revealed by traditional tools. For example, the adoption of abstract apparatus, such as the Universal Turing Machine,[2] that is capable of growing indefinitely, allowed architects to manipulate formally the concept of the infinite. By applying a generative algorithm for a number almost unlimited of iterations, it was possible to radicalise the formal experience previously explored in the eighteenth century by Ledoux, researching the infinite via the endless repetition of a geometric system.

Nevertheless the use of techniques deriving from science of complexity slowed down dramatically in the mid-1990s.

This state of affairs is because of two conditions:

Firstly, the direct transposition of tools deriving from other scientific fields presented many limitations. On a practical level, there was difficulty in controlling instruments whose mechanisms were not familiar to their users. In effect, since those tools were developed in the science of complexity, it was impossible to understand or manipulate their internal rules. Secondly, it was impossible to create a direct connection between the formulation of a problem, the enunciation of the expected performance of the tools used to solve it, its expression in a codified digital algorithm and finally the refinement of the tool itself.

In architecture for more than a decade the use of codified systems was mostly a digital utopia rather than a real practice.

Today, architects' interest focuses mostly on the Measurable dimension of the code. The goal is to develop architectural instruments capable of creating a direct relationship between the mathematical expression of a specific performance (formal, visual, static, acoustic, sensorial, etc...) and their constructive formalisation.

Where the field of the *Measurable* and the field of the *Non-Measurable* are concerned, architectural codes consist of creating new functions. To make an architectural code means to define a set of relations between the parts of a system.

2. The code as the creation of new functions

A code is the articulation in symbolic language of a conceptual model.

Some architectural problems can be managed with a classifier system, consisting of a set of rules, each of which performs particular actions every time its conditions are satisfied by a specific informational attribute.

To codify means to express part or totality of a project with an algorithm: firstly to articulate a problem by defining different levels of complexity starting from the most elementary units and the enunciation of their attributes; secondly to identify the properties and relations connecting the different elementary units; thirdly to translate them into rules or algorithms (starting from the simplest *nonlinear* expression as in the case of if/then rules); fourthly to organise them into a
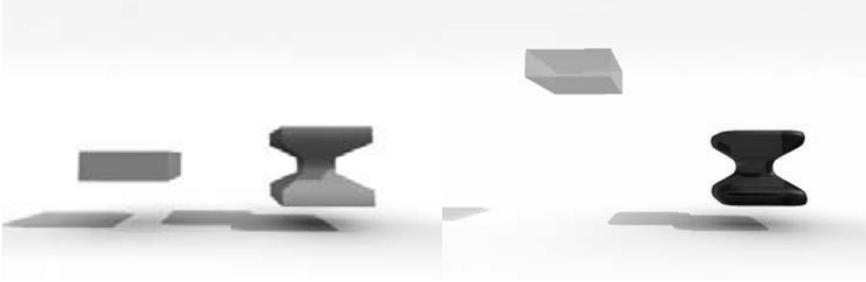
Figure 2

Example of parametric relation connecting two polygons

The change of the colour of the right polygon affects the Z position of the left polygon. Image by courtesy of

Nonlinear Solutions Unit, GSAPP, Columbia University.

hierarchical system expressing the way in which the rules are organised and perform (as is the case with tools such as cellular automata and genetic algorithms); finally to specify the conditions under which the rules will evolve over time (complex adaptive systems etc…).

In practice, building a code means making an idea by inventing a function.

This operation corresponds to the development of a real language.

In science, as in architecture, making a code is a creative act.
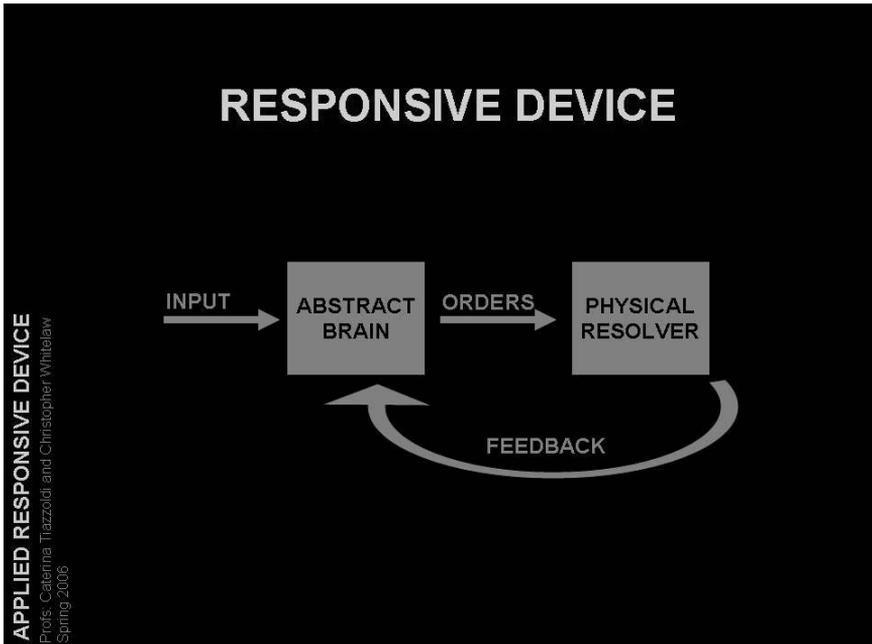
3. Applied Responsive devices at NSU

It is on the basis of the previous considerations that the research on Applied Responsive De-vices was carried out by the Nonlinear Solutions Unit at the Graduate School of Architecture, Planning and Preservation at Columbia University. The Nonlinear Solutions Unit, NSU, is an advanced research centre, whose purpose is to investigate the relationship between the meth-odologies and procedures developed in sciences of complexity and the solution of complex architectural problems. .

NSU operates on two levels: within the theory field by collaborating with various academic insti-tutions; and within the practical field, by working on specific case studies developed in collabo-ration with architectural and engineering firms.

Applied Responsive Devices operate as an educational and professional decision aid tool giving assistance to the decision-maker in fixing the priorities related to a formal, functional, techno-logical or engineering problem.

ARD also:

- Supports architectural reasoning through time-based simulations.
- Develops and refines the research tools through computational methodologies.
- Defines a strategy to allow the easy tracking of errors.
- Provides a conceptual and instrumental platform and a service to the scientific, architec-tural and engineering community.
- Contributes to the science of learning by providing an innovative methodology.

RESPONSIVE DEVICE

APPLIED RESPONSIVE DEVICE
Profs: Caterina Tiazzoldi and Christopher Whitelaw
Spring 2006

INPUT → ABSTRACT BRAIN → ORDERS → PHYSICAL RESOLVER → FEEDBACK

Figure 3

Applied Responsive Devices

Applied responsive devices create a direct relationship between the formulation of an idea, its translation in numerical input, the articulation of the set of rules or abstract brain connecting the input with the formal response of the physical resolver. Image by courtesy of Nonlinear Solutions Unit, GSAPP, Columbia University.

ARD's objective is to develop a direct connection between the expression of a specific expectation (functional, formal and aesthetic) and its achievement through the development of a code-based model.

ARD innovation includes the way in which quantitative and qualitative parameters (i.e. social, physical, sensorial, cultural and economic) are aggregated in order to emphasise the concept of formal adaptation.

From a methodological point of view the ARD process takes advantage of research done in other scientific fields (as in the case of research carried out by John Holland in the field of cognitive sciences).

In ARD methodology the first step consists of enunciating the expectancies and analysing the environment conditions, in translating them in elementary units and attributes that can be manipulated as the input of the digital model.

ARD's second step consists of defining the rules connecting the primary units and the hierarchical system organising them is the ARD *Abstract Brain.* The third phase identifies those architectural components which can provide an appropriate correlation between the input and the rules of the problem. Those elements are the Physical Revolver.
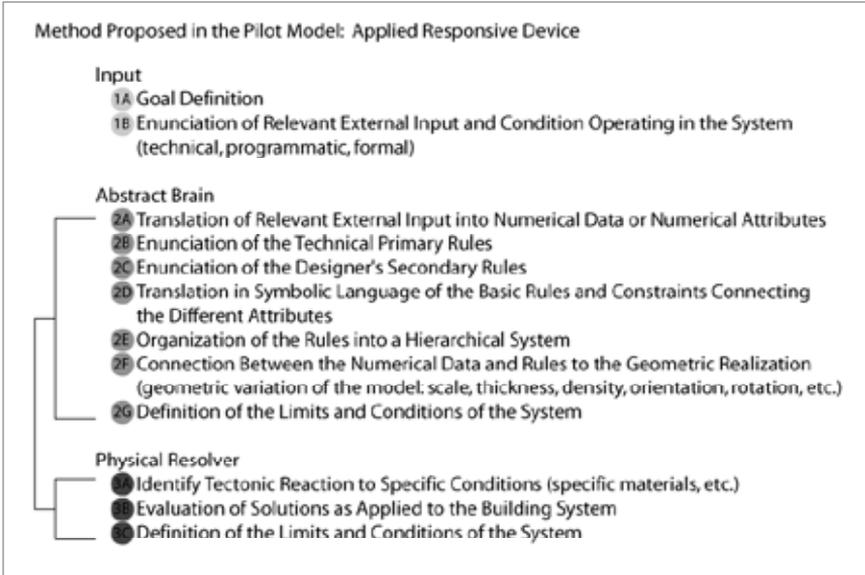
Figure 4

The various sequences of the pilot model Applied Responsive Devices

Image by courtesy of Nonlinear Solutions Unit, GSAPP, Columbia University.

In the last stage, a process of feedback will check and calibrate the system of rules of the Abstract Brain with the Physical Resolver tectonic solutions.

In this way, Input, Abstract Brain and Physical Resolver are closely entangled.

The interest of ARD lies in integrating, directly into a three-dimensional model, the constraints and the design formulations of the architect.

On a practical level, the possibility of connecting the apparatus of a project with an algorithm - for example, a system connecting the various components of a façade, the primary and secondary elements of a structure - allows architects to manage an increasing level of complexity in the design process. Indeed through the enunciation of a limited number of rules, it is possible to control the production of thousands of parts in a number almost unlimited of variations.

It is important to remember that, although the potential of new instruments seems endless, in the scientific and architectural world it is not feasible to work with models in which the number of interconnected variables is too high. In the scientific context, the case of Colouring Problems (below) demonstrates that it is almost impossible to work with devices that have more than four variables.

In the architectural projects, where the number of variables is obviously higher than four (social, functional, technological, formal, visual, historical and economic), it is not realistic to try to translate an entire project into a codified system.
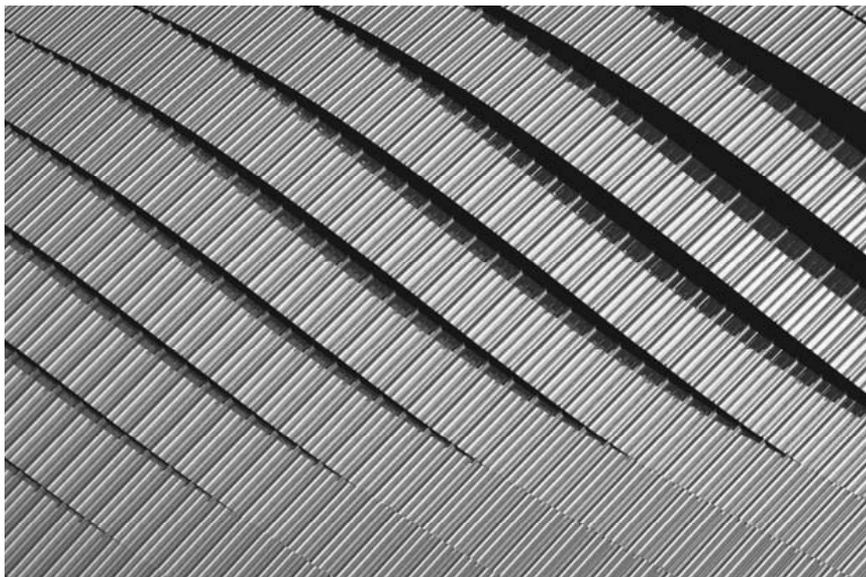
Figure 5

CASE STUDY 1 ARD1

Copertura, a finite-element model derived from a parameterised agent-based model organising sets of Kalzip tiles. A collaboration between NSU and Maire Engineering for the project New University of Turin by Sir Norman Foster and with Ken Tracy & Jeffrey Taras. Image by courtesy of the Nonlinear Solutions Unit, GSAPP, Columbia University.

The goal was to optimise the constructive process of a double curvature for the roof of the New University of Torino by using standard metal panels. The problem has been solved by applying the ARD technique. Firstly analogical data (such as the physical properties and the engineering limits of the material) were translated into numeric attributes. The length, width, flexional and torsion capacities were expressed as numeric input. Similarly, the final formal configuration of the roof was translated into numeric input. The translation in numerical data of final position x, y, z became the target of the replicating device operating in the system. In a second phase, NSU researchers developed a simple artificial intelligence embedded in the computer-simulated panels. They defined the rules qualifying the behaviour of the system: duplicate panels until the achievement of optimal configuration (established on the basis of an approximation to the final form defined by the designers). If the addition of a new panel would engender an excesses compared with the prefigured final size, the system would start with a new combinatorial sequence of panels until it found the optimal configuration. The process worked in a feedback loop operating a constant integration from analogical to digital data and vice versa. Image is by courtesy of the Nonlinear Solutions Unit, GSAPP.

In its *Measurable* dimension, the code can be used to analyse part of a problem: it can be used to model part of a given reality.[3]
One of the goals of the ARD research is to overcome the limitation of only four variables by using a combinatorial process as a tool of innovation. The project *Applied Responsive Device 4: Parametric Bookshelf* uses a combinatorial system to achieve an endless number of configurations of a bookshelf by applying a system of combinatorial local rules to the four attributes
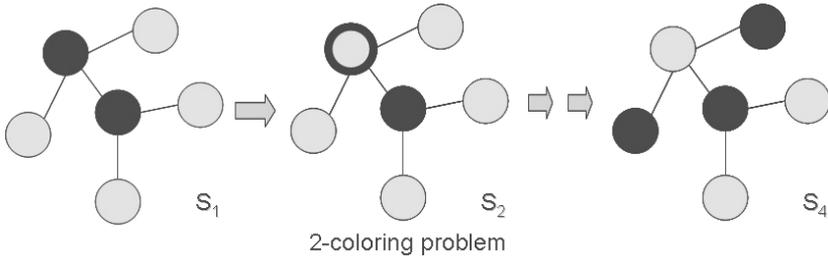
Figure 6

Colouring problems

An example of combinatorial optimisation of a 2-parameter system. The rule: none of the elements could be
connected with an element of the same colour.

qualifying the system (scale, thickness, colour saturation and depth). Parametric Bookshelf is a
bookshelf that has been designed with the objective of obtaining three types of performance:
adaptability of the size to different customers' requirements, capacity to unfold endless configu-
rations and finally to develop a system that is economically sustainable. The algorithm of Para-
metric Bookshelf operates on a double scale. On the global level it develops intelligence similar
to that of the project ARD1 Copertura. It specifies the modality of growth of the system. On a
local level a network of interdependent rules connects the four attributes qualifying Parametric
Bookshelf and permits us to obtain an unlimited number of configurations.

The goal of ARD, similarly to John Holland's concerns about the model, is to identify the correct
variables that are able to affect the development of a project meaningfully.

*The project Applied Responsive Devices 3: Formal Modulation for Light Performance in a Wom-
en's Hospital Façade* can also be considered as an example in which the application of a limited
number of variables permits the development of solutions producing a combinatorial innovation.
Each solution of ARD3 focused on the qualitative, and quantitative, understanding of algorithmic
responsive devices as applied to the constructed reality of a women's hospital façade system.
The goal of this research was to develop a project responding simultaneously to interior program-
matic shifts, the perceptive requirements and external site information. This task was achieved
by implementing an algorithm to connect the pattern of the window façade framing to the func-
tional, sensorial and technical requirements of the building programme.

In the case of ARD3 the idea of design performance did not refer not only to a criterion of tech-
nological optimisation, but above all to the client's request to obtain an inedited formal result.
Consequently NSU researchers developed a system of rules connecting the modulation of the
direct light with the different programmatic uses of the space (rooms, surgery rooms, waiting
areas, entrance hall).

Two strategies were developed for connecting formal solutions to technological performances.
The first one connected the rotation of a series of metal bars with the amount of light desired in
the various spaces. In a repeat performance this solution was re-interpreted in the project for
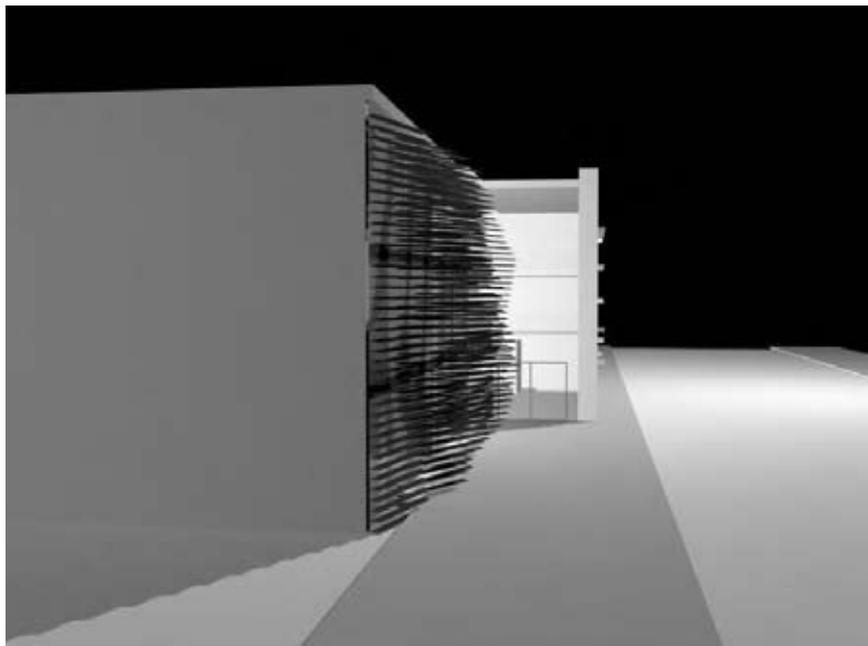
Figure 7

Applied Responsive Device 5

Formal Modulation for Light Performance in the building of the Enete Parchi of Vaude city, in collaboration between, NSU, Arch. Ilaria Cafasso and the architecture firm Nuova Ordentra, the rotation of the façade element depends to the modulation of the direct light in the building. NSU - GSAPP Columbia University, Fall 2007, Image on courtesy

Figure 8

Applied Responsive Device 3

Formal Modulation for Light Performance in Women's Hospital. Rotation of façade frames based on programmatic input, NSU - GSAPP Columbia University, Principal Investigator, with L. Yang, Client Impresa Rosso, Spring 2007. Image by courtesy of Nonlinear Solutions Unit, GSAPP, Columbia University

the building of the Ente Parchi of Vaude City – the result of collaboration between NSU, the architectural firm Nuova Ordentra and the architect Ilaria Cafasso.

The second project proposal developed in the context of the research ARD 3 *Formal Modulation for Light Performance in a Women's Hospital Façade* consisted of a number of diamond-shaped window elements. Each component had a solar panel placed in the front. The size and placement of the front panels were related to the modulation of the direct light penetrating the different programmatic spaces and responding to the curvilinear shape of the building. The algorithm was developed to fit any type of surface.

 Examples ARD 3, 4 and 5 demonstrate that the use of a combinatorial logic, achieved with a proper selection of the attributes and parameters acting in the project, permits us to overcome

Goal: Minimize direct light and maximize indirect light by blocking direct light and increasing the surface area of indirect light.

⊙ For each face of the facade geometry the difference between the face normal and the sun vector is measured and stored

⊙ Once the incidence is stored for each face, that data can be used to illustrate the intensity of the sun on the model by using the individual incidences to color the model

If θ = 0 the face is red
If θ >= 90 the face is green
If 90 > θ > 0 the face is the appropriate shade in the gradient

⊙ Using the incidence angle stored for each face the face will be extruded and tapered either outward or inward. The alteration provides more surface area exposed to indirect light

┌ Higher incidence means greater indirect light which will create a smaller extrusion and a larger taper

└ Lower incidence means greater direct light which will create a large extrusion and a smaller taper

Indirect   direct

⊙ The extrusion is based on a % of the surface area of each face to avoid disproportionate extrusions

⊙ The center face of the extruded face becomes opaque to block direct light while also creating a place for a solar electric cell. The four side faces become transparent to allow indirect light to pass through
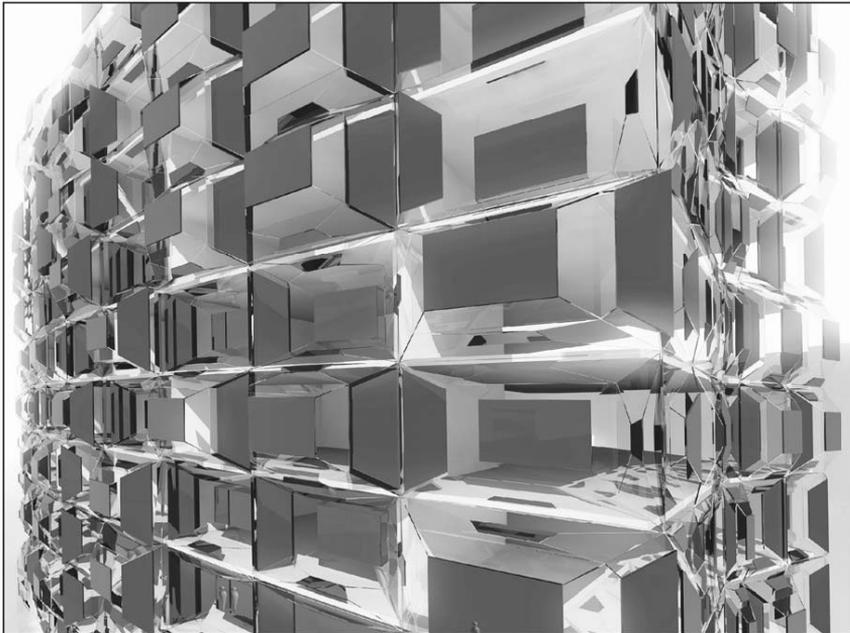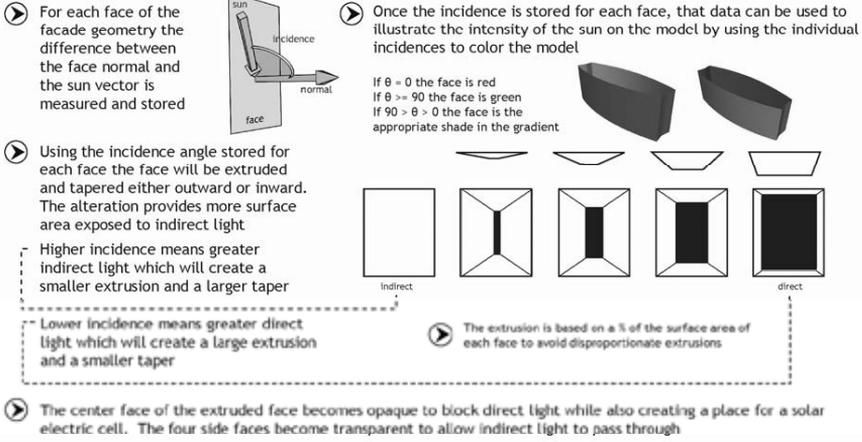

Figure 9

Applied Responsive Device 3

Formal Modulation for Light Performance in a Women's Hospital. Extrusion of façade frames based on the programmatic input of the building and the modulation of the direct light. The algorithm developed can fit any type of surface. NSU - GSAPP Columbia University, Principal Investigator, with Will Craig, Client Impresa Rosso, Spring 2007. Image by courtesy of Nonlinear Solutions Unit, GSAPP, Columbia University.

limitations on the use of a limited number of variables. The code allows us to treat many different situations. One of the potentialities of the ARD research is the capacity to embed the designer's intentions in the design process.

4 The codification and the definition of the new thresholds of the *Measurable* in architecture

A code is the network of rules representing the relations that connect the different components of a project. To codify means to translate a conceptual model, in a sequence of 1 and 0 that can be recognised, and therefore processed, by a computer. It signifies translation of any object or concept in a series of numerical attributes that can be manipulated as digital data.

This operation is easier when working with concepts belonging already to the field of the *Measurable* and having therefore a correspondent in numerical data (for example, the concepts of distance, weight, light intensity, weight, sound level, colour saturation, transparency, thickness). The numerical expression of entities that do not have a numerical correspondent in the first instance seems to be more a theoretical assumption than a reality.

To overcome the apparent distinction existing between *Measurable* and N*on-Measurable* elements, it is necessary to engage with the question of the boundary existing between hard sciences (mathematics, physics) and soft sciences (biology, sociology) and between the idea of objectivity and subjectivity.

According to Ilya Prigogine, the transition from classical sciences to sciences of complexity engendered the redefinition of the threshold between hard and soft sciences. In effect, Boltzmann and Poincaré's theories linked any type of observation to the subjectivity of an external observer: such a condition questioned the existence of absolute and objective verities. Consequentially they questioned the distinction between quantitative and qualitative, between objective and subjective. The transition between classical sciences to sciences of complexity blurred the boundary between the *Measurable* and the *Non-Measurable*.

John Holland, referring to the idea of creative reductionism, mentions the possibility of defining a new boundary for the *Measurable*. It is possible to redefine constantly the *Measurable* limits by connecting *Non-Measurable* entities with *Measurable* ones. According to Holland,[4] in cognitive science, 'any human can, with the greatest of ease, parse an unfamiliar scene into familiar objects – trees, buildings, automobiles, other humans, specific animals, and so on.'[5] This decomposition allows the translation into *Measurable* entities of elements that initially were *Non-Measurable*. Such an operation is a conceptual associative act that cannot be realised by a machine.[6] To reduce or to decompose a *Non-Measurable* entity in a set of numeric data is a creative act unfolding new fields of the *Measurable*.

Holland's idea of creative reductionism reflects some aspects of the Gilles Deleuze idea of concept-making. By connecting and putting in related ensembles of concepts it is possible to define new concepts.

Similarly in architecture the question is how is it possible to achieve the transformation of *Non-Measurable* in *Measurable* concepts that could be manipulated through a computer model? How is it possible, and is it legitimate, to manipulate numerically elements that usually belong to the field of the qualitative? For example, how could we translate the concept of privacy in a set of numerical registers? Is it possible to assume that we can reduce it to a set of spatial conditions (for example, the presence of visual and acoustic obstacles)?[7]

In such a context John Holland's idea of creative reductionism is finalised to reduce a situation to a set of attributes and building blocks that can be digitally manipulated. It implies the creation of a database or a classifier system that is able to grow endlessly.

It is therefore possible to create new definitions and to make *Measurable* what was not.

To connect, to express according with and association of pre-existent building blocks reminds us of Deleuze's idea of the manufacture of new concepts.

The translation of architectural ideas in code can be seen as an ultimate creative act challenging the boundary between the *Measurable* and the *Non-Measurable*.

Notes

1   Bertuglia C., Rabino G., Tadei R., La valutazione in campo urbano in un contesto caratterizzato dall'impiego di modelli matematici, (Torino: Celid, 1991);Bertuglia C., La città come sistema complesso: significato ed effetti sulla strumentazione metodologica e sulla prassi, nonchè sui presupposti concettuali che sono alla base della strumentazione metodologica e della prassi, (Torino: Celid, 1994);

2   Chu K., "Metaphysics of Genetic Architecture and Computation", Perspecta: The Yale Architectural Journal, no. 35, 2004, pp. 74-97;

3   Nevertheless the application of the code in the *Measurable* dimension of architecture most of the time is limited to bi-dimensional surface of a trimensionalised surface embedding a limited number of variables. In such a way it is possible to control the tools operating on the project. This is why in the last few years the architectural scene has been characterised by the use of codes limiting themselves to pattern-making on the top of a surface.

4   John H. Holland is a professor of Psychology and a professor of Computer Science and Engineering at the University of Michigan; he is also an external professor and member of the Board of Trustees at the Santa Fe Institute, a MacArthur Fellow and a Fellow of the World Economic Forum. His two most recent books are *Emergence: From Chaos to Order and Hidden Order: How Adaptation Builds Complexity.*

5   *From Chaos to Order* by John Holland available from: http://www.cscs.umich.edu/ ~ crshalizi / reviews / holland-onemergence /.

6   'This quick decomposition of complex visual scenes into familiar building blocks is something that we cannot yet mimic with computers', *Chaos to Order* by John Holland is available from: http://www.cscs.umich.edu/ ~ cr-shalizi / reviews / holland-onemergence /.

7   Legitimating such operations depends on the fact that any architectural concept, in order to become built architecture, needs to become quantitative information. Any design concept or sensorial performance to become architecture has, by the means of drawings and texts, to become a set of numeric inputs that can be transmitted to the executor. Any architectural idea is destined to become numeric expression. The principle of the code in architecture is to understand how much it is possible to anticipate this operation by transcription of an architectural project in a codified expression.