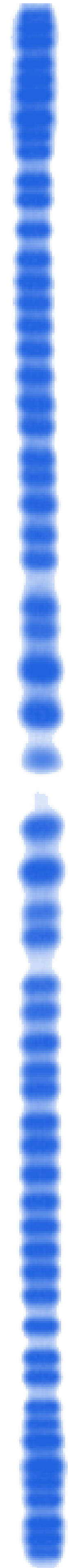

Designing a DNA for responsive architecture:
a new built environment for social sustainability

Gian Carlo Magnoli, Leonardo Amerigo Bonanni, Rania Khalaf, Michael Fox

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Abstract

The paper explores innovative environmentally responsible and socially proactive ways to build in developing countries. The proposed methodology was tested with the design of a Smart Village in Egypt, awarded the second prize in an international competition[1] . Our design approach is based on environmental and social sustainability and works as an artificial genetic code. This process generates the sustainable architecture of the village using the behavior of biological creatures in artificial systems. The design ensures that our architecture is nurtured by renewable energies and built with recycled materials. The disposition of public spaces and the flexible organization of different functions are conceived in order to stimulate social sustainability, allowing the community to be interdependent as much as an ecosystem. Local cultures, typologies, materials and climate build the DNA of both the village and its buildings. We apply concepts from artificial life, using "creatures" that follow simple low level rules in order to get high-level group behavior. By combining the principles of artificial life and architecture, we get both high energy-efficiency and optimal placement of built units on a specific site.

As in any ecosystem, a fractal, coherent, continuous fluctuation at every scale of the system is vital, and this kinetic flexibility is achieved at four levels: *1) decentralized urban planning; 2) reconfigurable spaces; 3) modular building blocks; 4) kinetic structures that respond to light, climate and people.*

Introduction

We believe that design has a great influence on people's quality of life. Nowadays this influence is unfortunately mostly negative. The built environment today worsens quality of life because it consumes large amounts of energy and resources, and pollutes too much[2] . Furthermore, the built environment creates segregation and self-segregation, contributing to social exclusion[3] .

How can an architect anticipate the unsustainable effects of design, and resolve them early in the design process? Current design methods have high social and environmental costs. Our Smart Village proposal outlines the criteria for a socially sustainable design process.

I a) - Why? Acknowledging the high cost of design

It is well known that conventional design has a high environmental and social cost[4] .

After the industrial revolution, human beings designed their built environment to meet an increasing number of basic needs. The immediate satisfaction of those needs forced designers not to consider carefully all the complex consequences of their action. Contemporary society runs on a high-consumption linear process of cause-effect, which generates waste and excludes large portions of the world population from the process. Up until today design has been mostly based on this cause-effect

linear process. This approach is not acceptable anymore.
Designers are today facing the need to deal with pollution, energy consumption and social capital, in order to reduce the ecological footprint, the embodied energy, and social exclusion caused by the built environment[5]. This stimulates architects to think about the impact of their future work, and ultimately about the social responsibility of architecture. When both environmental and social costs are to be considered, architecture becomes more sophisticated. Designers are asked to solve more complex problems, dealing with the consequences of their action, anticipating the long term cost from the beginning of the design process. This is what economists would call: "including the externalities in the budget". How can design achieve it?

I b) - How? Increasing efficiency by reducing costs: the analogy of the genetic code
New design methods must increase efficiency by reducing costs.
Geneticists are studying how to modify genetic codes to prevent diseases. If the built environment had a genetic code, we could design it in such a sustainable way that bad consequences could be prevented. [6] To design a genetic code we need to go back to the basics of structures.
A linear cause-effect structure fails to perform if just a single element collapses, because the cause-effect chain is interrupted. Design consequences are numerous and disturbances create unpredictable effects. A systemic structure has a highly-efficient, low-consumption circular structure where an element's waste equals another element's food. In ecosystems, as much as in human brains, the systemic structure performs even if more than one element collapses.
Genetic structures are always systemic. A systemic structure is proven to be more efficient than a linear structure[7]. We are exploring how a systemic approach to design can generate sustainable development, dealing with the huge number of information and possibilities.
To model such a degree of complexity we use computation, with the final aim to write a behavioral code from urban to building level.

I c) - Where to begin? The importance of nurturing social capital and its sustainability
Social capital is the most important capital human beings can deal with. It "refers to the institutions, relationships, and norms that shape the quality and quantity of a society's social interactions"[8]. And social capital depends on natural capital.The world's population has developed behaviors that negatively affect natural capital, resulting in an unsustainable environment.
Cities represent the physical expression of social convenience. They should nurture social capital. Instead, the built environment today is the main physical product of social development and yet is mainly responsible for the negative impact on both social and natural capital. Social Capital is the virtual framework of society, while the built environment represents the physical framework in which society can develop.
Ironically, the built environment stimulates unsustainable social behaviors[10]. Interestingly, in case of a crisis, social collapse normally precedes environmental breakdown[9]. A healthy social capital is diverse, interdependent, flexible, and capable of partnership and recycling. Consequently: sustainable. From a designer's perspective we need the built environment to contribute to social sustainability. We need architecture to respond to people's needs: the first priority is social inclusion.

I d) - What is proposed? The responsive built environment as a builder of social sustainability
Designers must reverse the vicious loop: the built environment – our field of intervention - should allow a synchronic efficient performance of both social resources and natural resources. Generating a sustainable, socially responsive built environment can contribute to solving the problem. The genetic code ensures that complex ecological thinking is used to generate social sustainability. The social environment must be allowed to be healthy, diverse, interdependent and flexible: open societies perform better than closed ones. Each individual has access to resources, can establish partnership and produce, constantly recycling the flow of energy and information. We propose a human-generated, computationally-modeled, open built structure that behaves like a healthy systemic society:

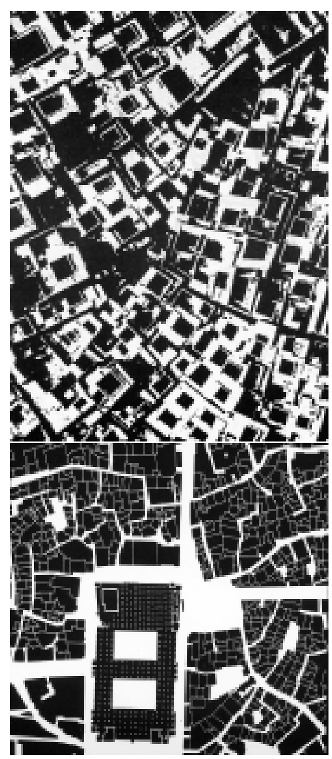
- Each building component has the same rights of any individual component of society: it can be plugged into a neural spine at any scale;
- Each architectural element can be combined with any other, has access to physical and natural resource, and responds to individual inputs;
- Each space and function can be adapted reconfigured, and customised by people, according to the democratic combination of individual pressures which leads to reducing both social and environmental costs;
- Each structure reacts systemically to the enormous amount of socio-environmental inputs.

In this way each designed element is able to add its pressure to the system and be involved in a partnership at four main levels:

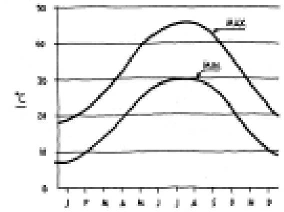
- **Decentralized urban planning;**
- **Reconfigurable spaces;**
- **Modular building blocks;**
- **Kinetic structures that respond to light, climate and people.**

1) Decentralized urban planning,

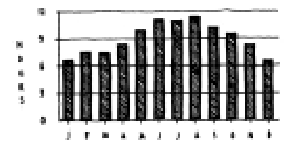
The primary motivation of the design lies in creating a design solution that is flexible and adaptive at any scale, and at instances, responsive and intelligently active with respect to the changing individual and climatic contexts.
Accordingly, the goal for the Medina smart Village was to provide a framework for flexibility that can be configured and reconfigured on two scales. Firstly, to satisfy the immediate desires of the community and users with the capability of adaptability and expansion to meet the changing needs of the village programmatic spatial requirements, and secondly on a local scale to optimize the building for changing environmental conditions. Such adaptability then aims to meet the changing needs of the users and their activities/environment for comfort and optimum spatial efficiency and thermal conditions.



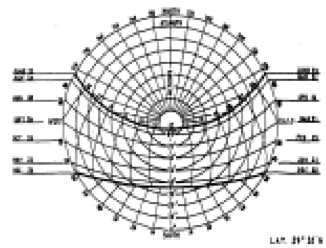
Through the framework provided, which is rooted in Arabic vernacular layouts of towns, numerous configurations can be satisfied to accommodate the “modular design” and “information technology” philosophies.
The Plan is organised on the Cairo Sun path: this allows that each building in the Village gets the right amount of sun (to power solar panels and PVs) and shadow (for comfort). The layouts can accommodate a small village approach by hosting different groups into protected, localized outdoor and indoor areas and office arrangements with equal access to common administrative and service areas. The urban plan exists as a single entity that adapts to localized contextual conditions.
The hexagonal – non-hierarchical - units are fabricated by a series of parallel walls, which act as a networked spine or sub-structure. The modular units metamorphose from strictly regular entities to spatial enclosures as defined by their specific function.
The honeycomb grid then serves as a functional framework for the natural growth of the urban fabric. As both users and natural environmental conditions define the hexagons, the spaces become increasingly varied, deformed and flexible in terms of usage. The hexagons serve to moderate the activities of the users and the environment and bring about their own definition. Smaller structures are allowed to plug into the “spine” walls of the hexagons creating a secondary layered fabric. The framework of the initial grid is flexible to a certain extent while maintaining minimal thresholds to allow for continuous infrastructure capabilities.
The secondary in-fill structures can then be almost literally plugged into the networked double walls of the primary fabric with infinite arrangement possibilities.



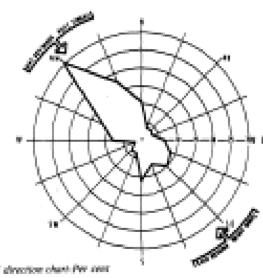
Temperature table-Centigrade



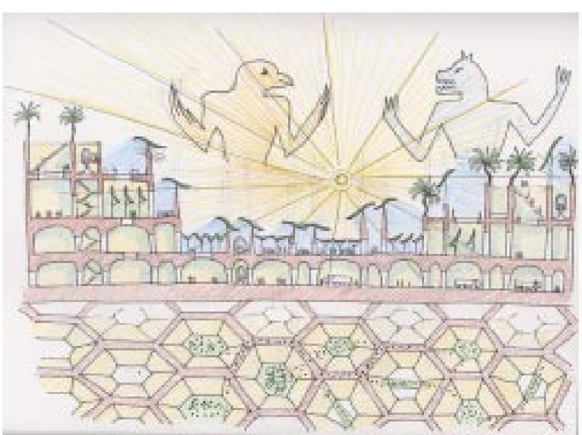
Sunshine table-Hours per day

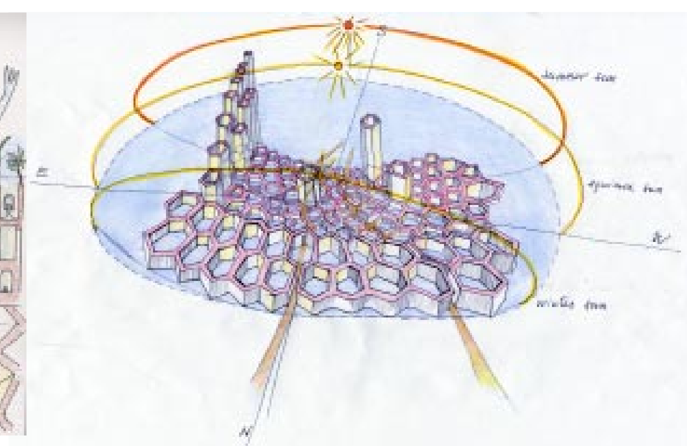


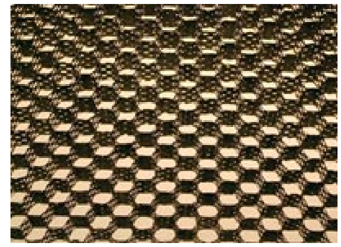
Sunpath diagram



Wind direction chart Per cent

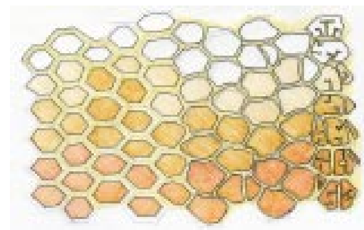




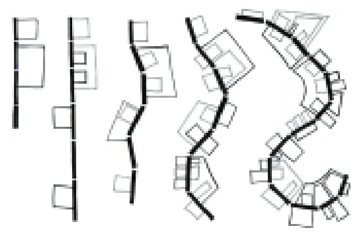


2) reconfigurable spaces, which allow a flexible adaptability

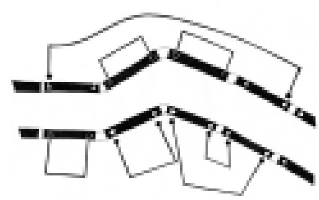
The scheme hinges on a modular “plug-in” corridor component that is assembled like train cars and serve to function like the chassis of an automobile. The 45 cm (~18") double walled components contain all of the necessary electrical/HVAC equipment and are attached to each other with a seamless flexible connection. The components - which can be either low-tech, locally produced or highly engineered, remotely fabricated - also provide the flexibility for re-configurable window and door layouts. Periodically along the walls are electrical and plumbing access that allow for a diverse layout of sink counters, drinking fountains, lighting, etc....



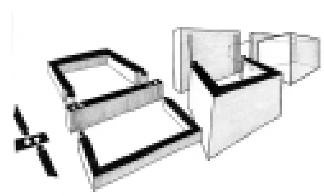
The rooms are attached to the corridor configuration with shared walls that can provide any two rooms with the capability of expansion to a shared common space. The systemic modularity of the system allows infinite shapes and combinations.



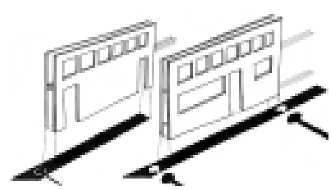
3)modular building blocks



The rooms are both small stand-alone single office rooms and larger covered spaces that contain smaller rooms within. In this way a large space such as the cafeteria would provide a thermally protected common area with the smaller support areas plugged directly into the spine. The building as a whole will demonstrate how transformable objects can dynamically occupy predefined physical space as well as how moving physical objects can share a common physical space to create adaptable spatial configurations. Adaptability may range from multi-use interior re-organization to structure transformability. General implications include an adaptable response to spatial efficiency and environmental responsiveness.

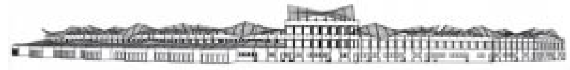


4) kinetic structures that respond to light, climate and people[11]

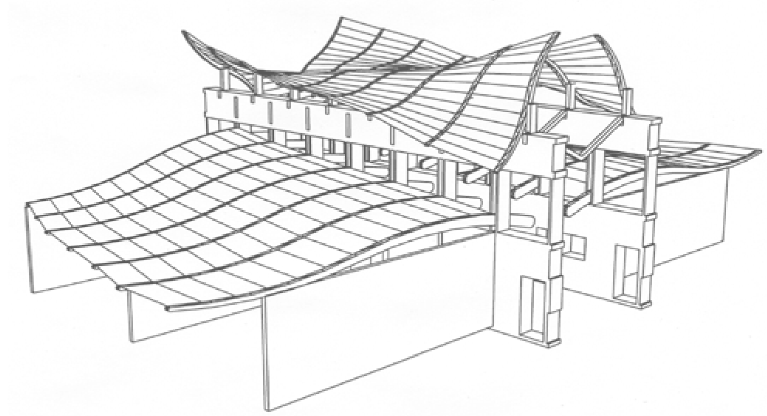


Buildings and architectural objects that use fewer resources and adapt efficiently to complex site and program requirements are particularly relevant to an industry that is increasingly aware of its environmental responsibilities.

Primary design considerations are to utilize natural daylight in the space without interfering with functional instructional and working visibility and to take advantage of natural ventilation through a dynamic roof system.

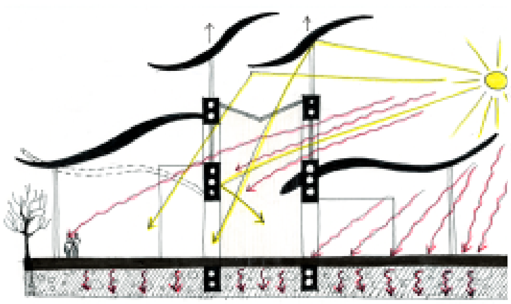


Since the sun changes position, the roof keeps moving like a living structure.

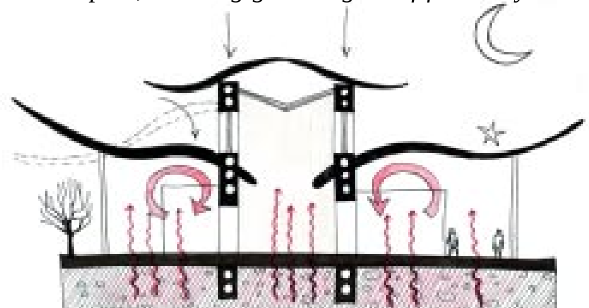


The dynamic roof system on the spine and a series of high operable windows on the spine allow for a wide range of response to changing environmental conditions.

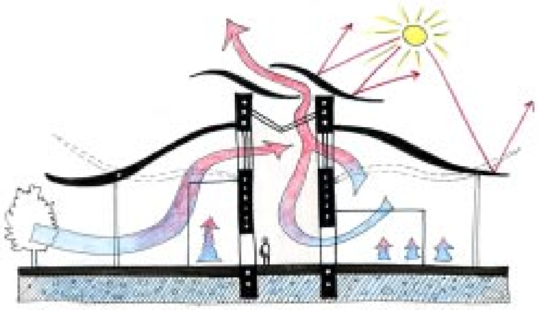
note how red (plumbing), yellow (electricity) and transparent (walls) elements plug-in into the spine, allowing great degree of flexibility[12]



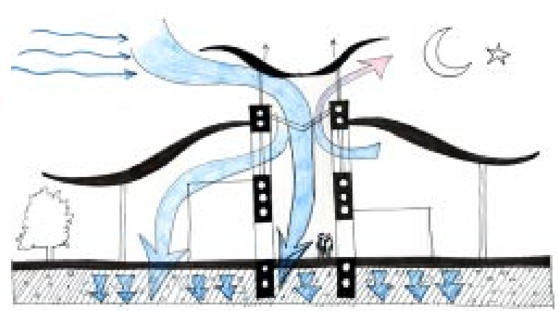
Winter day: the kinetic structure opens to the sun and its warm light



Winter night:
the roof closes on the warm thermomass



Summer day: the roof "denies" the sun allowing cross ventilation



Summer night:
the kinetic roof opens to the cool night breeze

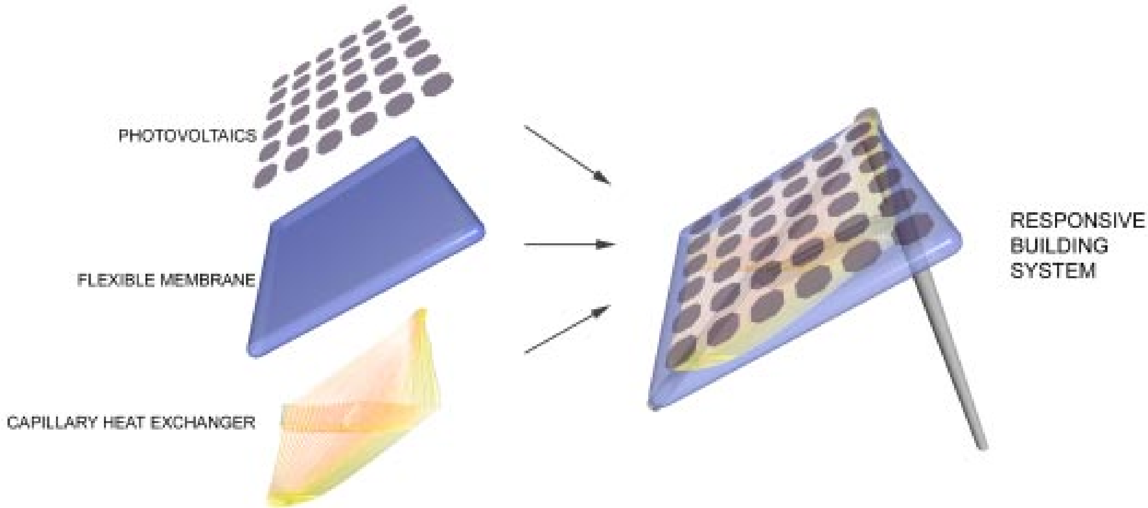


Diagram of the kinetic roof: the elastic, highly-insulating membrane is covered by amorphous silicon Photovoltaics on the exterior skin, while in the interior side a capillary system runs water to obtain a proper heat exchange. This element works like the leaf of a tree.

II – How? A new design methodology to produce socially sustainable architecture

We need a sophisticated design tool able to make buildings responsive to people. In this way healthy societies can shape their healthy built environment, symbiotically living within the natural environment. We have shown how at every scale the elements of the Village adapt to different conditions with diverse kinetic reactions, powered by the sun. At the urban level the request for a flexible spatial/ functional organization is satisfied by slow kinetic reconfigurability. At the building level the response to comfort/energy needs requires a continuous shape reconfiguration, achieved with more visible kinetic reactions. As in any ecosystem, a fractal, coherent, continuous fluctuation at every scale of the system is vital.

In nature any kinetic structure is generated to enhance performance. We are analysing if kinetic structures in architecture – which is mainly static – can improve Space Performance.

To further explain how computation can help modeling kinetic responses, vital to maintain the necessary complexity of the process, we shall analyze two of the previously described four levels:

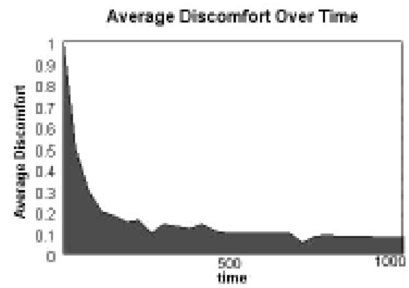
- the macro-scale “responsive city”, with its slow functional fluctuation;
- the micro-scale “responsive building element”, with its visible kinetic reaction to the changing context.

The methodology described in these two examples can be considered the paradigma of our design tool, applicable at all scales.

a) City planning: slow fluctuation

We model the DNA of a built unit as the description of its size, capacity, load on resources such as power and sewage. We also model the land used based on the optimality of location based on geographical and environmental attributes of each plot.

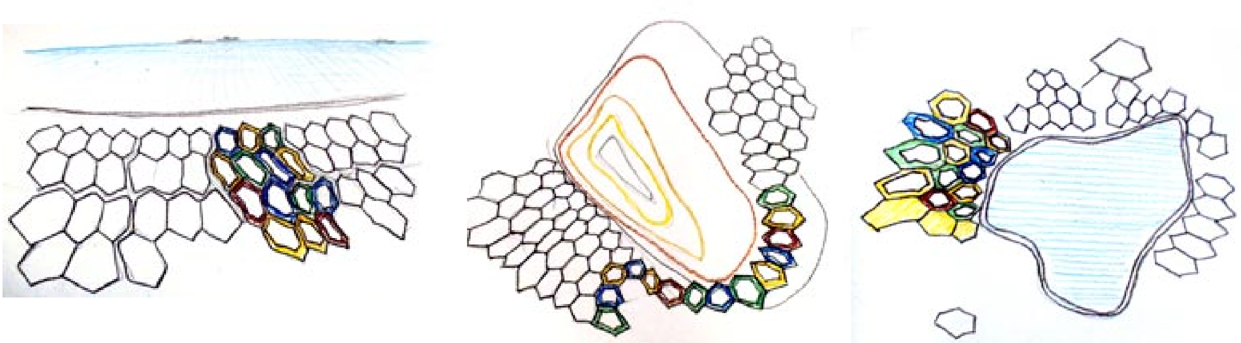
The concept of artificial life can then be used to optimally place units on a given area of land. An encoded map and a set of units are handed to a system that allows each unit to move around such that it is in a low-cost plot and in a comfortable pressure level. The pressure level consists of how much pressure it and its neighbors are exerting on the area in which it is placed. As the units move around to find their optimal location, the "discomfort" of the group drops. Giving each unit an ideal, maximum, and minimum viability level, the result will be a decentralized city with a distributed load on resources. This approach can be extended as the city grows.



The DNA analogy can also be used in the alternative scenario in which the location of units are given, but their size, density, and other attributes are to be decided such that their impact on the community is as positive as possible.

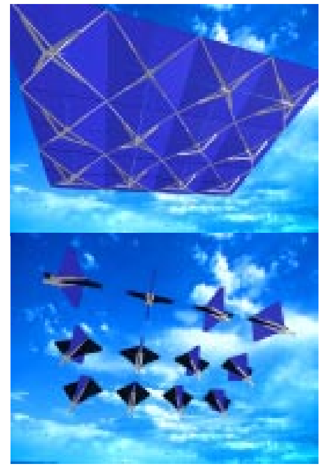
With the DNA consisting of attributes that can be toggled, a genetic algorithm may be developed where different generations of units replace the parent(s) until a fit child unit is found. The algorithm, by analogy, replaces each unit with another unit (child) whose attributes are slightly different from its predecessor and measures the cost of these attributes in that location. Child units are created by a mutation of a single parent's DNA, or if a sexual reproduction analogy is used, then it is a cross-over of both parent's DNAs or a copy of either one's. This may be repeated until a fit unit is found. Thus, instead of moving the units, this approach toggles unit attributes while they stay in the same plot of land. Results achieved from such an approach are not meant to be the final say in a how a city is planned: people must be in control of design automation.

Models can then be manually tweaked by the city planners or architects, with a resulting calculation of the effect of their changes. Attributes of land areas and built units can also be chosen to reflect what matters most for each individual project.



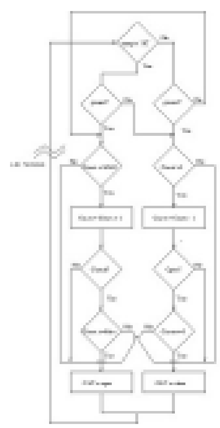
Socio-environmental pressure and urban development[13] : the units behave like cells

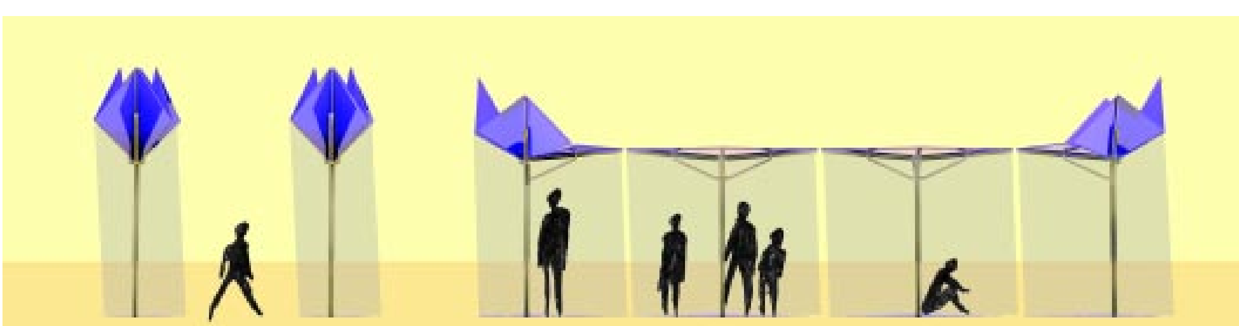
b) Building components: visible kinetic reaction



UMBRELLA CONTROL: The streets and squares of the Village are filled with umbrellas, whose design is rooted in the local culture, according to the Middle Eastern tradition to mitigate the climate extremes with tents.
They react to environmental conditions, prioritizing people's needs. These umbrellas are thought of as a responsive system to mitigate the discrepancies between environmental and social needs. They work as a neural system for buildings.
By modeling each umbrella such that it will respond to people staying under it for a long time, and people passing under it often, one can get a group of umbrellas to behave together. In the summer, people would like to walk under opened umbrellas in order to be shielded from the heat of the sun. While in winter, the umbrellas should open when it is very cold to preserve the heat that is in the ground. An infrared sensor, a thermometer, and a chip will be attached to each umbrella and will sense people passing under it at all times. When it is hot outside, and it receives a signal of a person under it within a two-minute period, the chip will increase a counter. When the number in the counter reaches its maximum value, the umbrella will open. If no one is under the umbrella and the counter is more than zero, the chip will count down. When the counter reaches zero again the umbrella is closed.

The opposite behavior takes place when it is cold outside.
The two-minute delay is there so that umbrellas on a heavily used path will open when it is hot even though no one stays under the same one for very long. Thus, when get complex group behavior where the umbrellas "learn" the most used path and respond accordingly to the behavior of the people using the space they are in. The logic can be easily carried out by a programmable chip, and the system diagram below as well as the flow chart provide an illustration and a specification of how that may be done.





III - Conclusion

If design is responsible for contemporary social and environmental damage, design has a great potential to repair it. Our work aims to create a systemic design tool to generate highly-efficient, low-consumption urban structures, from both social and environmental perspectives: architecture then becomes one of the means with which a society can blossom.
As much as environmental sustainability is the main need of balanced ecosystems, social sustainability is the aim of balanced society. Creating social sustainability means maintaining social capital[14] : social sustainability is therefore the starting point when designing the built environment.
We can therefore conclude that if societies behave like ecosystems, their social sustainability implies environmental sustainability. Hence our Smart village prioritizes social inclusion and quality of life, considering energy efficiency and reduction of pollution good consequences of the design process.
Architecture responsive kinetic performance becomes one of the means with which society builds its own sustainability.
The architect should design a built environment which sustain a systemic, interdependent structure of the social capital, allowing a healthy relationship between people, social capital and natural capital[15] .
The built environment can contribute to solving the problem by being responsive to people. Architects can then do their part, reducing social and environmental costs by designing a more inclusive built environment, making sure that people can interact with buildings, shaping their needs.
Social systems must be allowed to achieve sustainability, and what architects can do is to create a built environment which stimulates the ecosystemic behavior of society.

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RESOURCES:
For more information on systems of agents, refer to:
www.swarm.org and
http://www.ai.mit.edu/projects/ants/.

For more information on artificial life approaches to artificial and biological systems, refer to:
http://www.aridolan.com/ and
http://www.brunel.ac.uk:8080/depts/AI/alife/home.htm
http://www.cs.ucl.ac.uk/research/genprog/gp2faq/gp2faq.html

For more information on Kinetic Design, refer to:
http://kdg.mit.edu

For more information on Energy, Renewable Resources, recycled materials, refer to:
http://www.oilcrisis.com/
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http://www.doc.mmu.ac.uk/aric/eae/index.html
http://www.nrel.gov/
http://www.ciwmb.ca.gov/GreenBuilding/Materials/default.htm

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http://www.designawards.com.au/ADA/00-01/ENGINEERING%20DESIGN/082/082.HTM
http://www.evworld.com/databases/storybuilder.cfm?storyid=107&first=7906&end=7905

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Notes

[1] Medina Smart Village, http://architecture.mit.edu/~carlo/medinaindex.htm

[2] Herbert Girardet, The Gaia Atlas of Cities, Gaia Books, London, 1992.

[3] Richard Rogers, Cities for a small planet, edited by Philip Gumuchdjian, faber and faber, London, 1997.

[4] United Nations Environmental Programme (1999), Global Environmental Outlook 2000, UNEP, Nairobi, 1999

[5] Talbot, R. (1996). Construction and Sustainability: Alternative Future or Future Shock? Scottish Journal of Architectural Research, Vol 1. March 1996.

[6] Taken from: http://www.sigmaxi.org/amsci/issues/Comsci98/compsci9801.html

[7] Capra, Fritjof. (1996) The Web of Life: A New Synthesis of Mind and Matter, London: HarperCollins

[8] "Social capital refers to the institutions, relationships, and norms that shape the quality and quantity of a society's social interactions. Increasing evidence shows that social cohesion is critical for societies to prosper economically and for development to be sustainable. Social capital is not just the sum of the institutions which underpin a society – it is the glue that holds them together". From" What is social Capital? World Bank Group – More on: How is Social Capital measured? Cit.

[9] Talbot, Roger, (1997). 'Towards the ecological society: a toolkit for community learning', in Proceedings of the Conference on Environmental Justice: Global Ethics fore the 21st century, University of Melbourne, October, 1997, edited by N. Lowe. 21p. http://www.arbld.unimelb.edu.au/envjust/papers/allpapers/talbot/home.htm

[10] City of Edinburgh Council. (1998) The Lord Provost's Commission on Sustainable Development for the City of Edinburgh, Edinburgh: City of Edinburgh Council

[11] Kinetic responsive clean technologies are already being commercialised in the real world: ensuring both economic feasibility and maintenance for our "Smart Village" is vital too.
It is worthwhile quoting the case of self-sufficient kinetic boat: the Solar Sailor is an Hybrid solar/wind/battery/LPG 100 person electric tourist catamaran featuring kinetic "solar wings" able to sail and collect solar energy.
This boat operates with good success a as a conventional cruise vessel in the competitive tourism market on Sydney Harbor, in Australia. The 25% higher up-front cost is being compensated in a very short period: The positive first year performance allows the designers to estimate a 5-year payback period.
Maintenance is easier and less expensive, because the vessel has less moving parts than a conventional one: *"The vessel needs little in the way of the traditional maintenance you'd find on either diesel boats or conventional*

sailboats with their massive spares and rigging. He pointed out that the vessel's twin electric motors have but one moving part. The computer system has no moving parts and neither do the solar cells on the wings. Only the mechanism for lowering and rotating the wings moves". From: http://www.evworld.com/databases/storybuilder.cfm?storyid=107&first=7906&end=7905

[12] The authors designed this prototype in the House_*n* Lab (The MIT House of the Future) – Spring 2001.

[13] A CONCEPT FOR THE DRAFT OF THE PROGRAM:

```
public void move()
{
int action = calculateAction(currentLocation);
//gets position that improves happiness
if(action > 0)
{
changePosition(action);
//move there
happiness = map.getBlockCost() + getSelfPressure
+ environment.getpressureFromOthers;
//update the creature's happiness
}
//if action is zero then stay in same place
}
```

[14] "Social sustainability means maintaining social capital (…) Social Capital is investments and services that create the basic framework for society" - The World Bank Environment Department Papers #74 "*Toward Environmentally and Socially Sustainable Development*" - Environmental Management Series, Social and Environmental Assessment to Promote Sustainability - An Informal View from the World Bank, by Robert Goodland - January 2000.

15 "Humanity must learn to live within the limitations of the biophysical environment. (...) This means holding the scale of the human economic subsystem (=population x consumption, at any given level of technology) to within the biophysical limits of the overall ecosystem on which it depends." Robert Goodland, op cit.