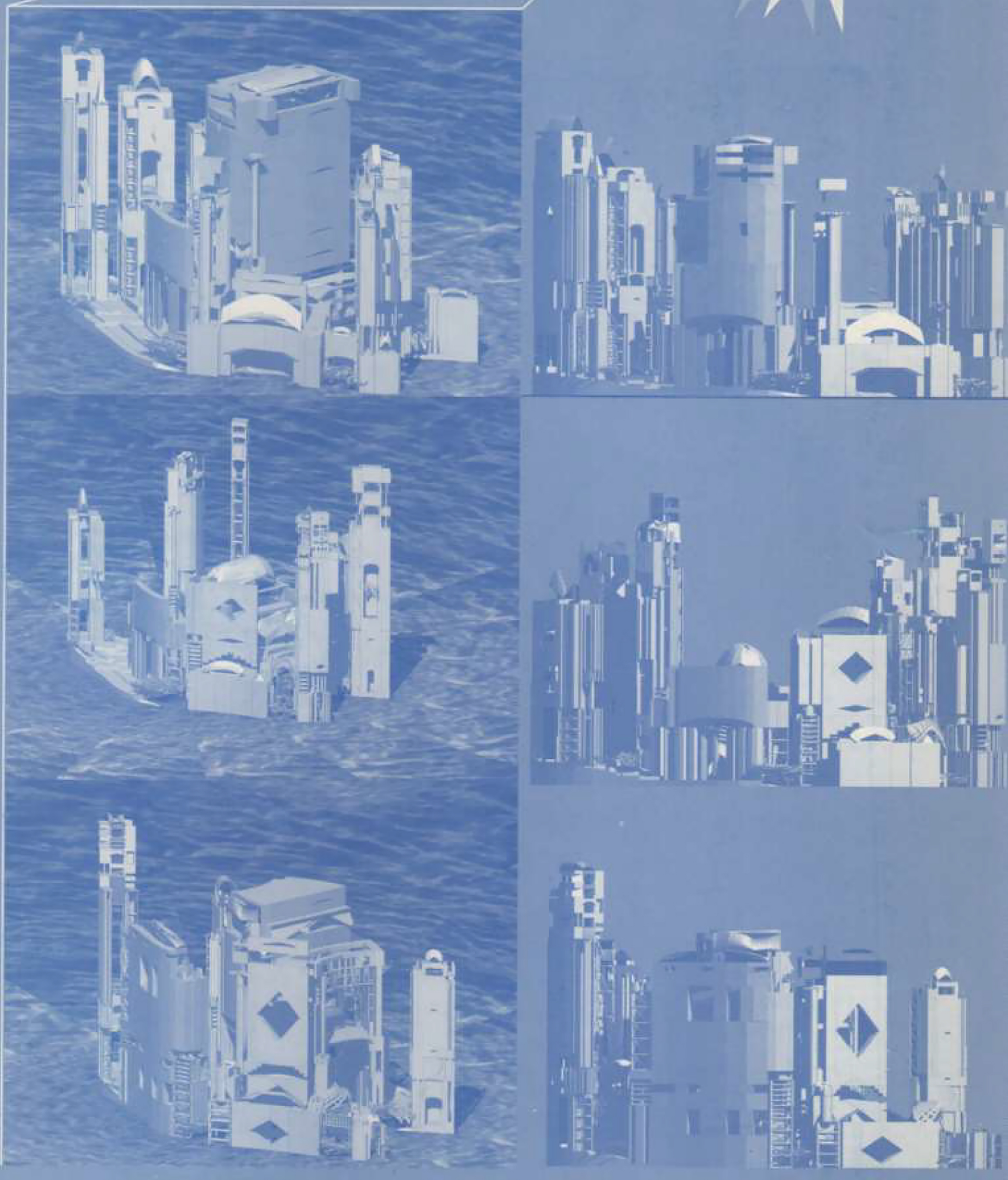
GENERATIVE ART 2002



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INDEX Papers

“La Citta’ Ideale”
Generative Codes Design Identity

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Abstract

The aim is: how cities could fit the quality idea, the urban lifestyle that is our welfare dream?
But what is our dream? A city that reflects, as in a mirror, our identity.
We know very well what we want: beauty, harmony, naturality and safety. For gaining them, we need to define "how" to satisfy these needs.

1. We look for **naturality**, but in the same time we love sophisticated answers to our needs. And naturality that fits human needs is a result of high quality design and management approach.
2. We are looking for **beauty and harmony**, but we are loosing these qualities, that we had in the past, in these convulsed improving density cities that satisfies only pre-defined and functionally optimized necessities
3. But first of all we need **clarity** and **safety**; and we discovered that also what appeared as impossible and unthinkable catastrophe was happened. And Safety can be realized only if each people can share a process of evolutionary conscience.

The complex structure of a city can be identified as not-linear complex system, and we need a tool that can emulate and manage, operating in real time, the transformation process of cities.
As all the dynamic not-linear complex systems, every city has a proper attractor, a specificity that countersigns it and that we can represent with a series of specific codes of transformation, with a Generative Project. Like DNA in nature, we can design the city’s identity

Ideal City, Piero Della Francesca atelier

1. Ideal Cities

Ideal city has always been a fascinating matter.
The thought of possible urban scenarios were **always representations of cultural approaches**.
These researches and utopias have produced visionary scenarios that tried to conjugate functional, aesthetical and symbolic aspects with those belonging to a good government able to realize the aspirations of citizens.


Lorenzetti, the good city government

The ideal city is a concept of possible, not a defined form. An adaptive concept that is able to fit the dynamics of the incoming transformations.
Ideal Cities are ideas in progress, cultural approaches, tensions toward possible existing cities, proposals that people can share giving his contribution that mirrors his uniqueness, his own ideas, desires, traditions and aims. It is ideal in how much it unites in a project an identifiable and characterized physical and social organization.
The idea of an ideal city is a philosophy, is a challenge, is how to look at future, how to think the increasing quality process. And this process must fit and support local culture and traditions.
Every cultural identity has, as art expression, its ideal city. This possible city represents the possible evolution of a *particular* existing city, traced using **codes belonging to local cultural reality**, to genius loci, to a recognizable urban identity expressed by its history. The ideal city of Venetians is Venice in its future possible configuration in progress. The dream is Venice incomparably much more Venice than before.

The idea of a city is, therefore, a visionary representation of modes of changing the city itself. When this idea is realized, the possible moves itself forward, looking for a new possible.
More, some cities are open cities. Who arrives feels so well as if he always lived in that place. And these cities are really impressive for the fact that, despite their inhabitants have different traditions and cultures, and different needs, the city's identity remain however so recognizable and unique. And **all different people recognize themselves in this city**.

2. How to look at future

The city must answer to the increasing requests and needs of its inhabitants, but above all to the **unpredictable subjective needs of each individual**, who "lives" the city following his own thoughts and his own desires and his own conceptual paths.
The fields of relevance of these requests are manifold:

1. Contradictory requests concerning artificial and natural ware;
2. The needs concerning the recognizability and the preservation of differences;
3. The esthetical needs;
4. The needs of security;
5. The functional needs concerning the adequacy, in real time, to the evolution of human life:

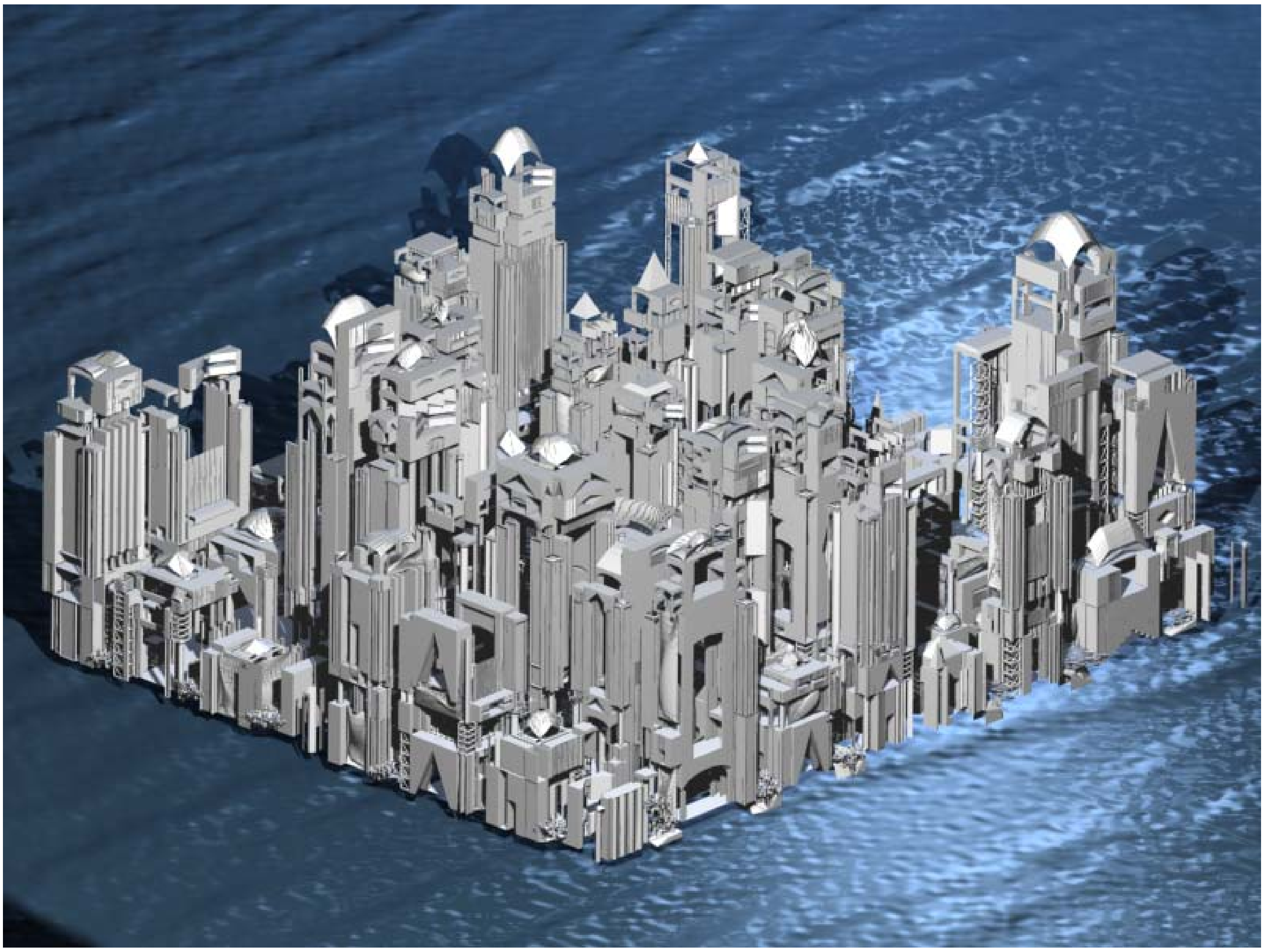
6. The need to find in the cities the patina of time that tells us we are alive because we had a past.

But all these needs are not so easily classifiable in optimized data that are legitimate for all people. Each of us is unique and unrepeatable, and our needs are, above all, subjective needs. The city, to be livable, must know how to respond to the unpredictable subjective requests of each of its citizens.

The city must be adaptable to the multiplicity of subjectivities, but in the same time must be recognizable, unique and, more, it must preserve its identity.

A precise relationship exists among the subjectivity of needs, the city identity and security of living there.

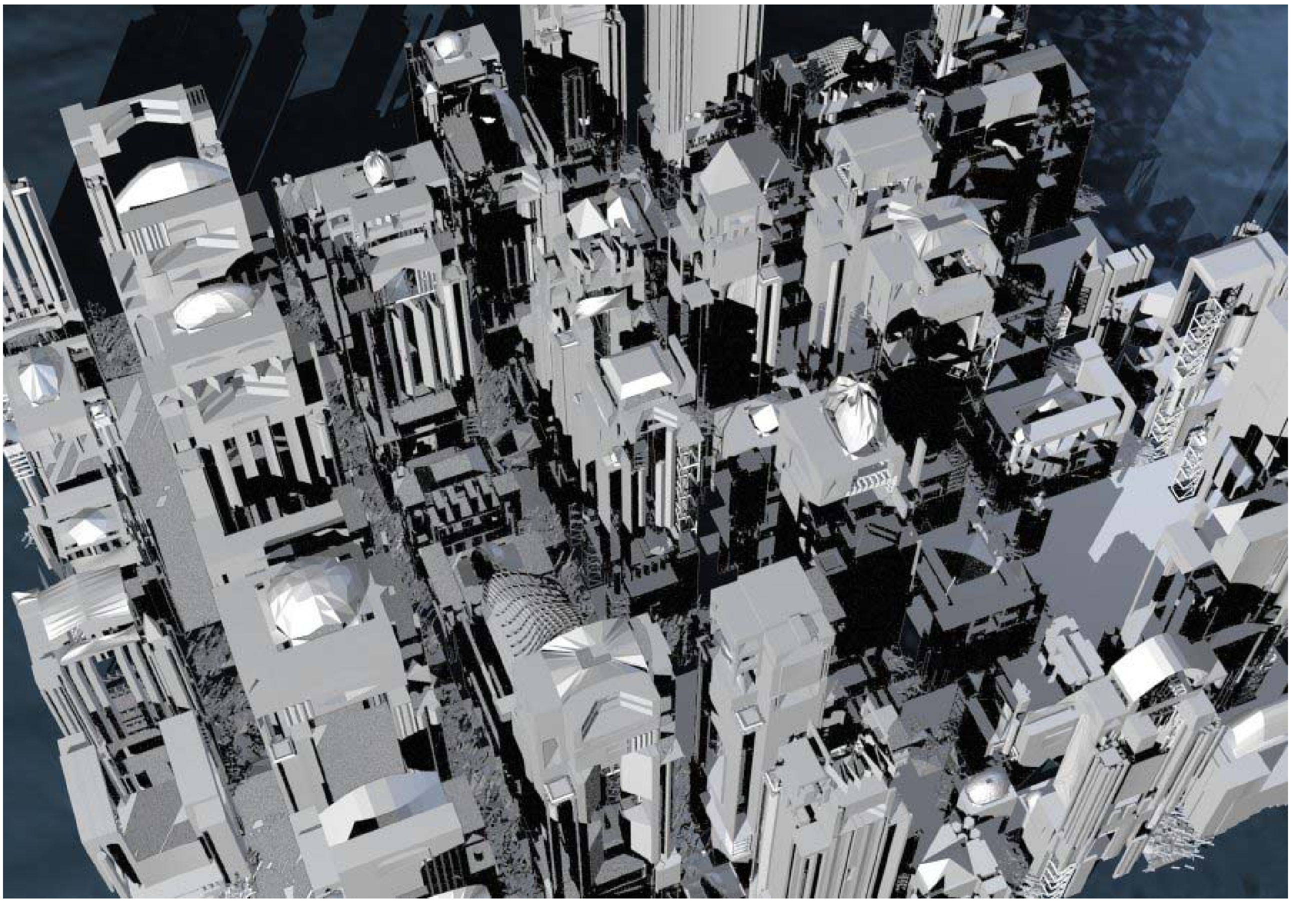
Everyone needs to live in an environment that respects the uniqueness of its inhabitants. This is possible only in a city in which identity, difference and oneness of environment is saved too. A town environment homogenized by an approach following only optimization standards contrasts to our subjective search of the happiness, to the sense of our presence and existence. (Soddu, Colabella, "recreating the city's identity", Freiburg 1995)



3. Generative Projects

Therefore we can identify a possible approach to pursue the urban quality in even more complex cities: not the construction of a static system, with previously defined events, but the **construction of a dynamic system and its logical rules** in which the initial paradigm, the conceptual structure of the city, is a first step of a reference process able to support and carry the subsequent dynamics toward the attainment of the quality.

The urban quality is tending towards quality. Quality will be reached when the build events represent our time of human beings in the history process.
The most opportune operational approach to the future of quality, safety and harmony of the cities is to manage the not-linear dynamic system that represents each city with a **Generative Project**.
Manage, re-design and design the town system. Generative urban design must define a paradigm of management, in progress, of the increase of complexity and not a plan proposing, in axiomatic way, forms and static orders.
This design act, and the strong clarity that springs from it, is essential.
The impressive matter is: identity, complexity and quality of cities can be **designed**. We can create the identity of a city putting together a sequence of creative acts, stratifying manifold different points of view, manifold concepts of city belonging different fields of interest, and constructing something like an artificial DNA performed like a table of transforming codes. These codes are not only theoretic but operative devices too.
We can use this **artificial DNA to emulate evolutionary sequences of city's life through increasing complexity processes**. Doing that we can generate new cities with a strong identity belonging to this artificial historic life. But thought these visionary scenarios we can, above all, identify and manage the existing cities and their quality.
The essential points of reference of generative projects are: identity, complexity, harmony, clarity and safety.



Generated city. The identity belongs to the transforming rules used and to the self-organizing paradigm that manages the process. The identity generative code used in this town design is my interpretation of New York City Identity through an operative generative meta-project

4. Identity

Cities are extremely complex systems. Each city has and must have its own strong identity, due to its own cultural tradition, strongly recognizable and loved from people living it. If a city has not identity, it's not a city; it's only a built-up area, a primordial broth without structure. We can transform it into a city, if we identify a concept strongly related to the environment and to its inhabitants. Our challenge in globalization era is: **a city equal to an other city doesn't exist**. Each one is unique and unrepeatable. We have to work for that. This is the reason why it is not possible to look for optimized solutions usable for all urban realities.

But, as often happens, increasing complexity due to the increasing needs of contemporary life can deteriorate this identity. And **cities can loose their identity**. Contingent solutions owed to specific needs and new functions can weaken this identity until loosing it.
It happens, above all, if the city's management forgets the harmony and the cultural specific identity and operates transformations that are repetitions of evolutions used in the other cities. The immediate functional objective can be reached but this approach can damage the harmony and the clarity of the town system.

Singapore. Generated architectures with the aim to fit a particular town concept that identifies Singapore.

But what does the "identity" of a city means, and **how is it possible to save this identity** from destruction, from the homologation of the image and from the flatting of its performances?
We can follow **two** different paths that come from different and contradictory presuppositions.
1. A way is to save the existing events by freezing them, because we read the environment identity as belonging to a particular static equilibrium. But this approach run the **risk of transforming each**

city into a museum and could not be an approach that brings us far. At most we can apply this approach to some exceptional existing events. The city, considered as a structure which identity is static, doesn't evolve and die, totally losing its real living identity.
2. The other approach, even if it is more difficult to manage, sees **the identity as developing procedures**. These procedures, sometimes consolidated by time, act controlling the increase of complexity, and represent the culturally unique and unrepeatable matrix of the site.
Like an olive tree that, overworked from the wind and from the rain becomes more and more an olive tree. It enhances its own identity, while, if grown protected in a bell of glass loses its own identity because it has not the occasion to explicate and represent its character. Following the same way, each city explicates its own identity living the perpetual shifts of cultural moments and unpredictable events, living and using the occasions created by the increasing of complexity of the life of the man, and of his needs, but also created by the chancing of each subjective approach.
This way is, however, much more complex than the first one, and more difficult.
After 11th September, I thing that we must rebuild Ground zero with a strongly positive image of our era because we believe in human progress and, as our fathers made before, we must leave to our sons a Hope space and a Beauty place.

If we choose this second dynamic approach**, we certainly cannot identify the city's identity with a database of forms or solutions** that reflect, in their specificity, different historical and evolutionary moments. Identity is not already savable through the repetition of facts and events. Identity is a *modus operandi* toward the future.
We must conceive something different from old planning tools: **a generative code, an evolutionary code that interprets, in the specificity of the contemporary moment, the bringing forward an idea, going toward the increasing of identity and recognizability of each city**.
We could identify as "**clarity**" the goal to be reached. Every new event that is realized in a city, also in specificity, unpredictability and novelty that can countersign it, it has to bring an increase of clarity.

Every new realization must increase the identity of its city. The city must make a footstep toward the attainment and improving of its unique city's idea, that is not necessarily tied up to specific forms, colors or recognizable events but to a recognizable logic representing the cultural and ideal character of this city.
Because each city, to be livable, must have a recognizable idea. There is not a static possibility: **the identity can be or improved or loosed**.

5. Clarity and Safety, the Livability

The relationship between the citizen and their city is a relationship of mutual clarity. Each people recognize his own city and, recognizing himself in this city, works for increasing the livability of the environment in which he lives.
Recognizing the city in which lives, each people finds, mirrored, his own identity of man.
Livability is harmony, safety, feeling good, feeling to be at home and sharing a city concept that reflects own history.
Clarity is, above all, sharing the evolutionary process of conscience, knowing what surround us and feeling it.
If we share the cultural concept of our city as code, we feel home, and we perform, in fractal way, all spaces following this code. From urban spaces to architectural spaces until interiors.
The urban scenarios emerging from these operational logics have, simultaneously, clarity of image and structure, recognizability and harmony and, in the same time, they fit the complexity of contemporary cities.

But this not means that urban spaces are all equal. On the contrary.
They are only like individuals of the same species. **Every urban and architectural space, unique and unrepeatable public - private events, will propose, in its oneness, multiple variations of the identity of the same place**. A city inside the city, each one different but able to interpret and represent the same urban idea.
Everybody as part of the same living entity, as inside a historical district in which life flows without interruption and all people know very well where they are, also if they never visited this particular place before.
Identity means that each inhabitant has a clear concept of his city, also if it is a megalopolis.
Because the complexity is understandable applying a fractal logic.
Each quarter, each place, each square is different and, perhaps, unpredictable for the citizens. Because it was realized in different moments and with the support of different designers. Each place may be unpredictable and fascinating for its uniqueness but it will be not a surprise for inhabitant people. The place is recognizable as belonging to the same city's idea.
Each people recognize each space, knows it and, discovering its unpredictable uniqueness, unconsciously improve its quality and clarity. As happened in historical ancient quarters. Or in natural environments where each people can valuate if something can be a problem because he knows clearly the structure of nature and he wonders looking at the multiplicity of uniqueness.

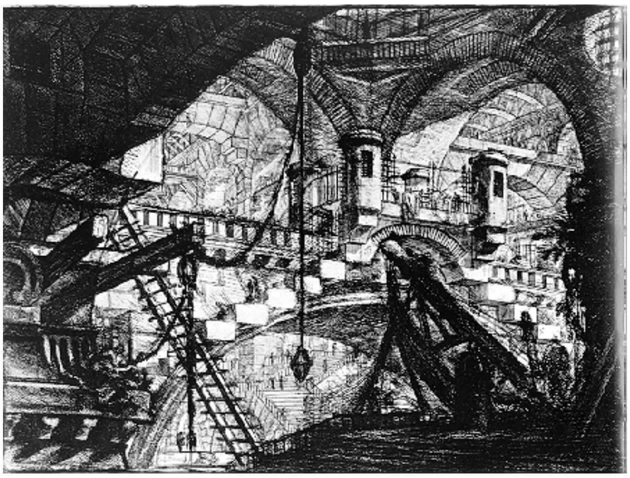
6. Naturality

In other terms, we can valuate incoming **megalopolis as a new naturality**. Where complexity is not a character that brings difficulties but, as in nature, can help the approach to identify and manage problems and new needs.
More, this approach to complexity can, unpredictably, satisfy the need of naturality of town's inhabitants. All different events, but clearly recognizable, perform a natural quality. Where artificial **events are all different like in nature**. And, with their uniqueness could mirror the uniqueness of each human being that lives the city.
Generative approach performs these possibilities.
Using a Generative Project, we can generate a sequence of different possible incoming scenarios, and valuate them. In the meantime, we can verify and control the structure of evolutionary process we have designed. All the results generated by this project are different, really complex like natural sites and fitting the complex needs of contemporary life.
These results define, in the plurality (we could say the endless) of possible figured scenarios, the identity concept of a city. Each generated town design is a performed Ideal City because this generative project is not only a solution but a way to look at future and to design the mailfold future possible evolution of the city.

7. Complexity

.
Complexity and not complication. Complexity fit clarity and quality. On the contrary complication fit confusion.
It is extremely difficult to define the complexity as static attribute of an event, of an environment.
Complexity is not only the result but also the **same structure of an evolutionary dynamics**. It depends, essentially and entirely, from the "how" the system-object-project-environment-city that we are considering is evolved.
It is in fact impossible, and unthinkable, to directly produce complexity at once without activating and attending the evolution of a dynamic trial. A process of accumulation of following results and possible different points of view and, contemporarily, of progressive synthesis acts.

If, as architects, we try to imagine ex-novo, and to extempore draw a city that has the character of an environment with complex historical stratifications, we will go toward to a sure failure and we would probably produce simplified sketches.
In the past Piranesi too, drawing visionary cities, used to stratify, in different times, a plurality of possible histories, transforming the previous one in way to leave traces and forms that progressively accumulate and evolve themselves. His drawings are **complex because they represent traces of life too**.


Piranesi, visionary complex environment


Giotto, medieval city image

Complexity is ever connected to the dynamic path of transformation. It is born from this process. **To design and manage city's complexity we must run its evolutionary process**. And **Generative Design does it**.
But if dynamic trials of development are necessary to produce complexity, these are not enough to reach complexity and not only complication. Something further is needed.
A city increase its complexity from the length of the lived time, but also, and above all, from having crossed different historical and cultural moments, programs of development conceptually different and contradictory, and from the ability of simultaneously living these different points of view concerning its development.
A generative tool managing the increasing of complexity (and belonging complexity, quality) must emulate two types of growth: the **accumulation of events** and references (due to the trial), and the **performing of clarity**, due to the growth of the ability of continuous self-organizing of the system in front of what changes, also suddenly.

But not only. Complexity also manifests itself with the ability to effort (we could also say to react in front of) these events, satisfying incoming needs unpredictable before. This ability is an attribute that we can identify and define as self-organizing power of the system. Managing the changes in progress to maintain entire, rather to increase, town identity, quality and characterization. (Soddu, Colabella, "Il progetto ambientale di morfogenesi", environmental design of morphogenesis, Esculapio Publisher, 1992)
Generative approach produces projects able to emulate self-organizing processes and to design complexity.

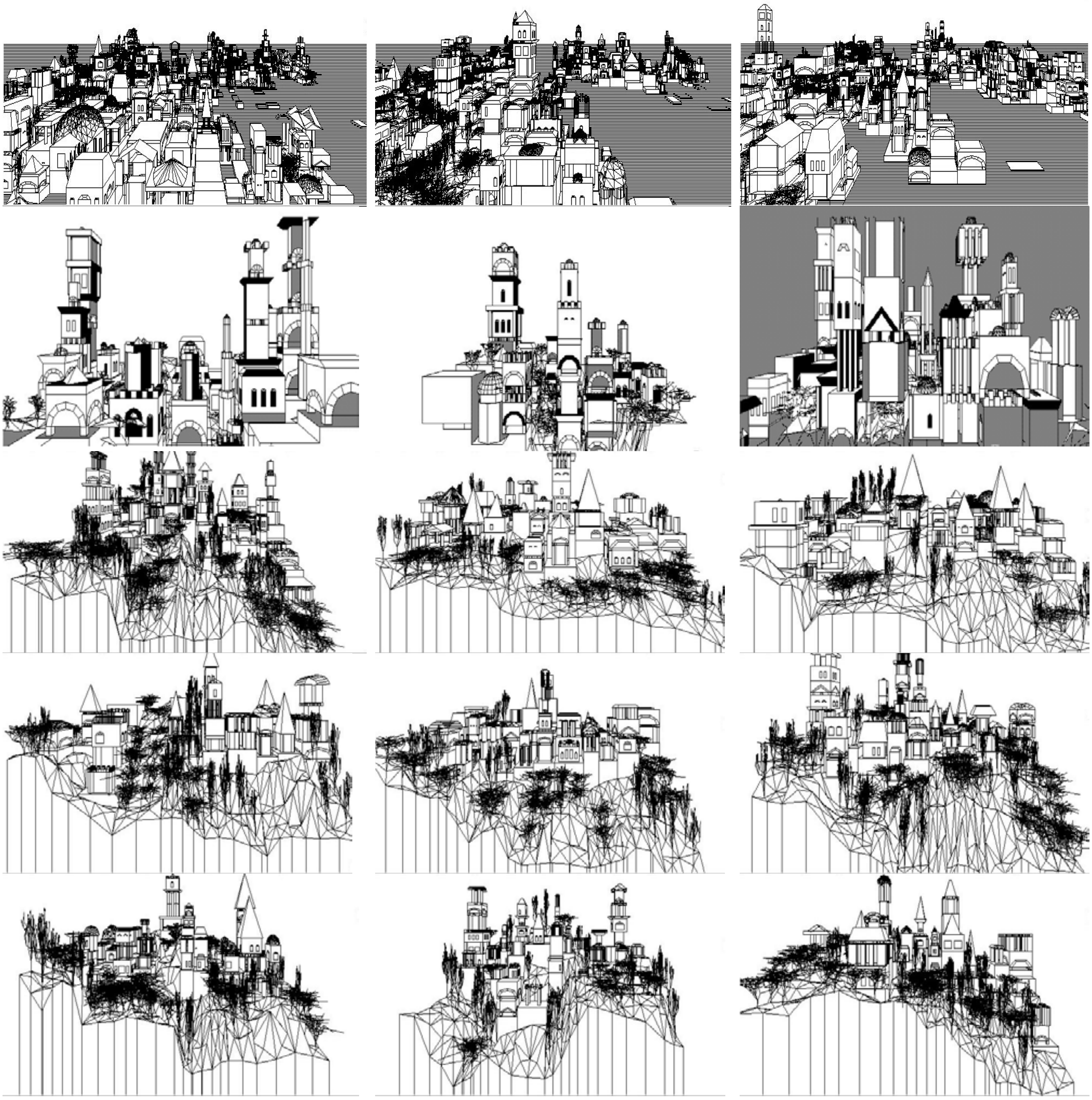
8. Case Studies

One of first case studies that I realized was the generative project of **Italian medieval towns Identity**. (C.Soddu, Citta' Aleatorie, Masson publigher, 1989 Milan, Italy)
The urban image painted by the Italian masters of '300 and '400, have been one of the occasions for my experimentation. Looking at these images I have tried to represent, through algorithms, design logic and an urban evolutionary logic. The aim was to understand, identify and represent the "urban and architectural character" of this city's concept.
For the characteristics of the research and of the tool that I had in mind and I was setting, this was a theme that has not been developed looking in preference at the philological and historical references, but operating only through harmony's stimuli that some pictorial images of medieval time are still able to give to me as a contemporary designer and architect.

To do that, and to find a composition reference with the more univocal possible identity, I observed a whole series of images of urban spaces and architectures represented by Giotto and Simone Martini

Simone Martini, cities scenarios

The operational choice has not, however, the setting up of a library, an abacus of elements to be composed, because this approach would have been able only to furnish "predictable" images, therefore far from the complexity of possible urban systems and urban shapes that I was looking for.
The aim has been, above all, the **representation of a conceptual dynamics**, of logics through which such elements (at the various scales) can be produced. And the representation, in parallel, of the temporal dynamics of construction of the urban shape.



Generated scenarios of medieval Italian towns (1989)

Each generative devices, separately, acts on different aspects of the same element. They are activated by the simultaneous presence of different logics.

Artificial Life emulation is used and the generative project is structured in way to produce also absolutely unpredictable elements. But such elements, generated using the formal logic rules identified to fit the medieval town identity, are strongly recognizable as “medieval”. The three-dimensional models generated with this project have the “patina of time”. They belong to recognizable spatial orders, scenarios that seem to be produced by a temporal run, by a common “history”.

Unpredictability comes from the different time of starting up the artificial design life, not from using random factors inside the code. Generative codes are strongly identified transforming rules and the aim is reaching different results but belonging to the same identifiable architectural concept and town idea.

Two scenarios of Rome's "Borghetto Flaminio". The increasing complexity sequence using medieval and baroc transforming codes

Another case study was **Rome**. The historical center of Rome is certainly one of the more complex city environments. Its complexity is directly in relationship with the ability to preserve, rather to increase, its identity and characterization through different and discontinuous historical and cultural moments.
In this study case the design approach for a new project inside this historical center was to identify different codes of harmony as transforming rules and apply them to manage increasing complexity. Particularly, these codes of harmony were performed trying to fit, with a design hypothesis, three of the most important historical and cultural steps of Rome: Imperial age, medieval age and baroc. These **codes were dynamic contemporary interpretations of historical rules**.
We applied, in sequence, these transforming codes of harmony to manage the "clarity" of final results. At the end a "**Generative Project**" was realized. And this project was used to pursue the concept of increasing identity of Rome identifying and performing a contemporary approach to complexity were future scenarios will have the memory of stratified cultural references as time patina.

This approach works because the design idea is a concept of possible future scenarios performed as operative metaproject, and is not only simplified with a form. The idea, performed as Generative Project, is a code of transformation, a set of rules that can start up an evolutionary process that can manage the increasing complexity and identity of an artificial environment in reaching ever more levels of quality and satisfaction.
The generative approach fit the new concept of town design.
The last experimentations were about **Hong Kong, Los Angeles** and other cities.

Hong Kong waterfront, generated sequence of skyscrapers.

Hong Kong waterfront, increasing complexity and identity

I designed a DNA of these cities and I used that to perform incoming new scenarios.
The idea was:

1. Find **the identity codes of these cities, fitting the concept approach to multi function semi-public semi-private architectures**. These codes avoid to simplified town organization but pursue a fractal complexity: each space is like a town inside the town, and so on.

Two different scenarios of the same evolutionary generative architectural project in Hong Kong

2. Design a **set of transforming codes** that can represent the identity of these cities.
3. Experiment these codes generating a sequence of different and unpredictable scenarios that reach the aim:
   a. **An increasing complexity** of the city
   b. **An increasing identity** of the city

To verify that, I generated sequences of urban scenarios as improvements of existing scenarios.
I presented these scenarios in public exhibitions to verify how this increasing complexity of their city could fit the evolutionary ideas of its inhabitants. Results were impressive and exciting talking with exhibition's visitors, especially young people.

Hong Kong Central, behind the HSBC, increasing the site identity and recognizability.
A generated new building.

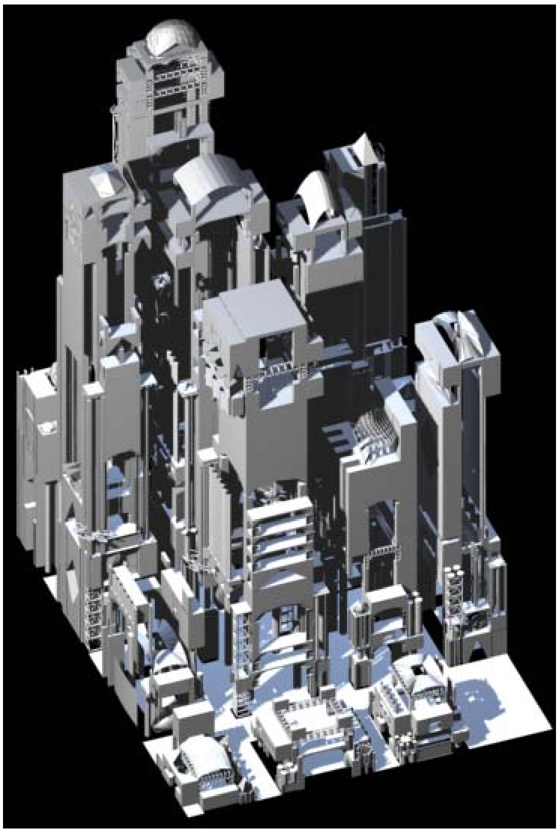
The reason was that the inhabitants discovered that their city could increase its identity!
Now, I am working in visionary evolutionary scenarios of other cities: Washington DC, Macau, Shanghai, New York.
The verified that citizens of these cities recognize themselves in these generated evolutionary scenarios.
So the subtended Generative Projects work. And it's possible to use it in managing the evolution of cities. More, it's necessary if we intend to preserve these city's identities.

9. Codes of Harmony

.
The first step, in generative design, is to construct the set of codes that identify each city. We could call them codes of **harmony**. And we can perform, with them, a generative town project.
Italian Renaissance culture had identified the harmony as logic linked to the process of construction of artificial environments, to the systems of relationships and proportions that tie different events inside architectures and cities. The harmony therefore is a logic that defines the modus operandi of designing acts.

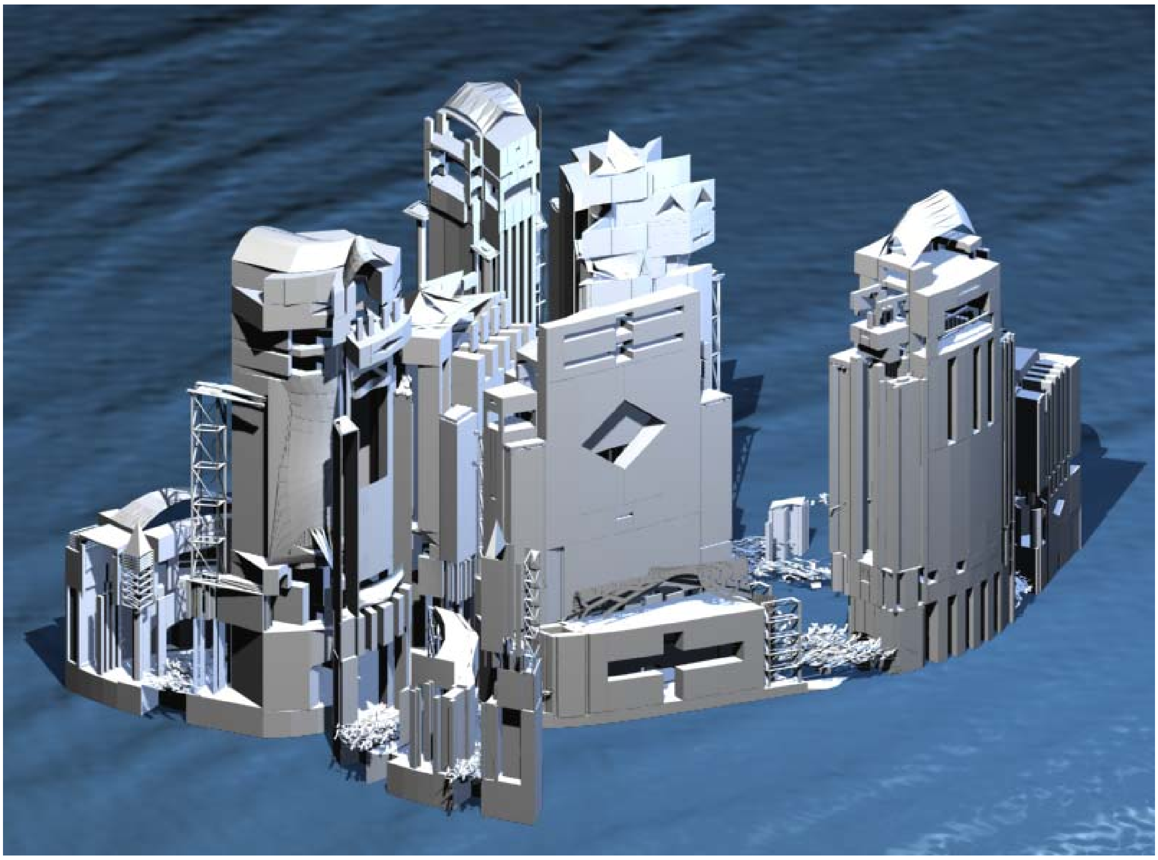
Hong Kong waterfront in the night. A generated new architecture.

New architecture in Hong Kong Central

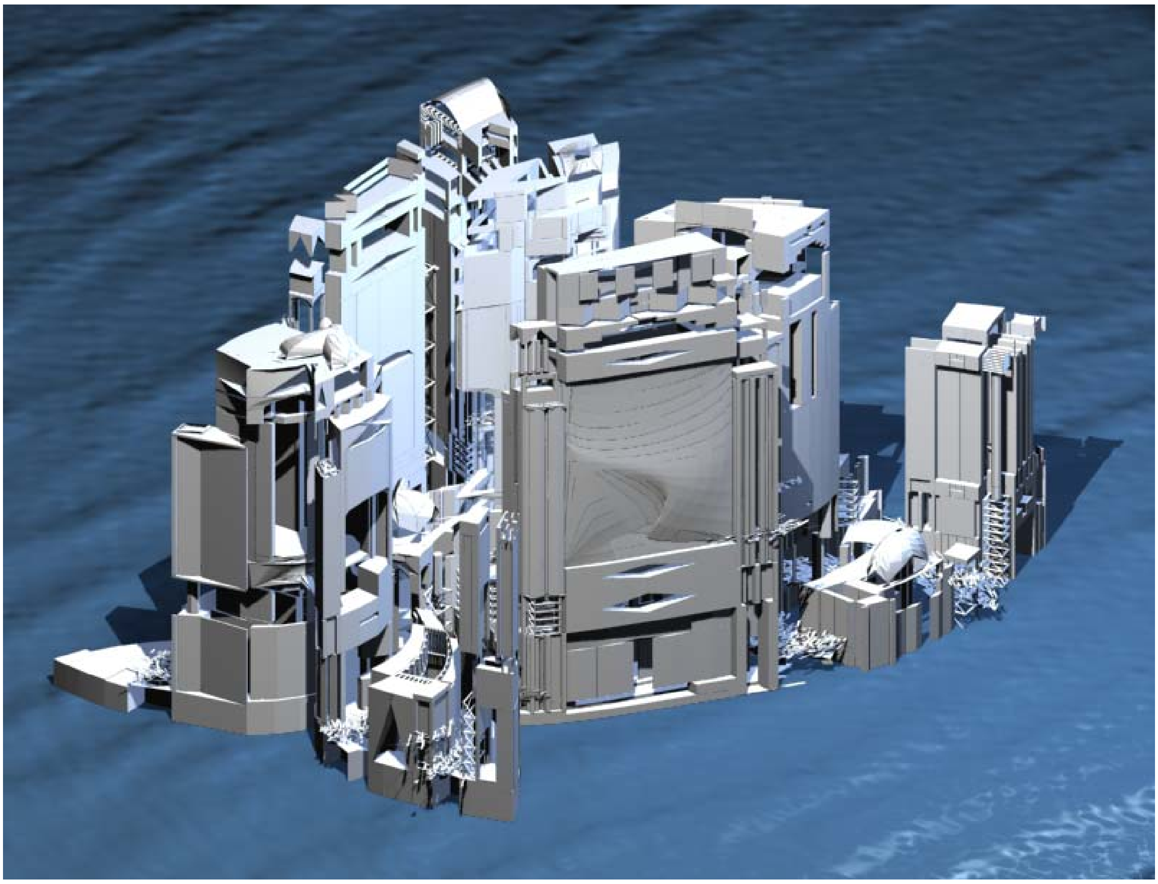


A generated multi function semi-public semi-private city block

Los Angeles, generated architectures to increase city identity.



Two parallel generated urban scenarios for an Asian city on the sea

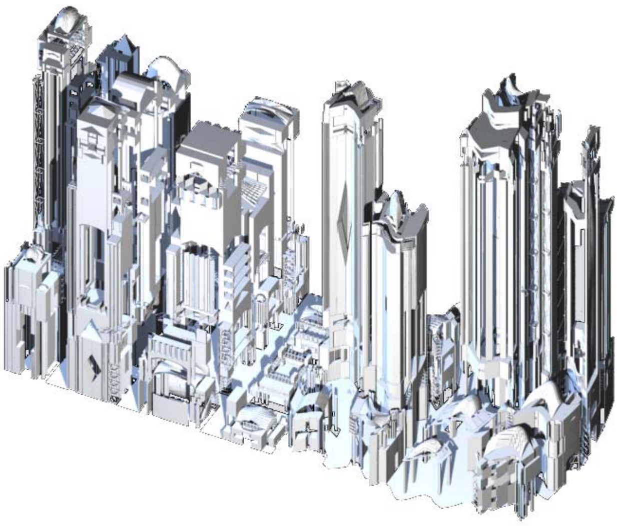


The codes of harmony, in the different cultures, has always been the way to find and use, in the construction of artificial environments, the logics that is possible to read in the natural world.
These logics are strongly tied to each different culture even if it is possible to find a common substratum between different traditions in the processes of interpretation of nature.
These logical rules, interpreting nature, define dynamics of transforming environments toward harmony. These rules are a design synthesis of the manifold aspects belonging to the construction of possible scenarios.
The operational hypothesis to manage the evolutionary dynamics of cities is to identify and to realize, as generative executable projects, the codes of harmony that represent specific urban identities.
We can do that through some different phases:

A. **Identification of urban dynamic transformations** proper of a specific city, reading, as rules of transformation, the historical evolutions of the city and the contemporary tensions. Particularly it is possible to identify and to codify these evolutionary rules as:
   - Structures of dynamic progression of the **spatial dimensions**;
   - Structures of progressive transformation of the **topological relationships**;
   - Rules able to control the progressive scenarios represented through **perspective visions**;
   - Sequences of **rhythms** and progressive discoveries of urban space;
   - Contemporary presences of events structured in dynamic relationships among the **dimensional multiplicities** of the built;
   - **Coincidences and contradictions** between the existing spaces and those possible;
   - Relationship between whole and parts, activating controls on the dynamics of **fractal sequences** proper of complex systems.

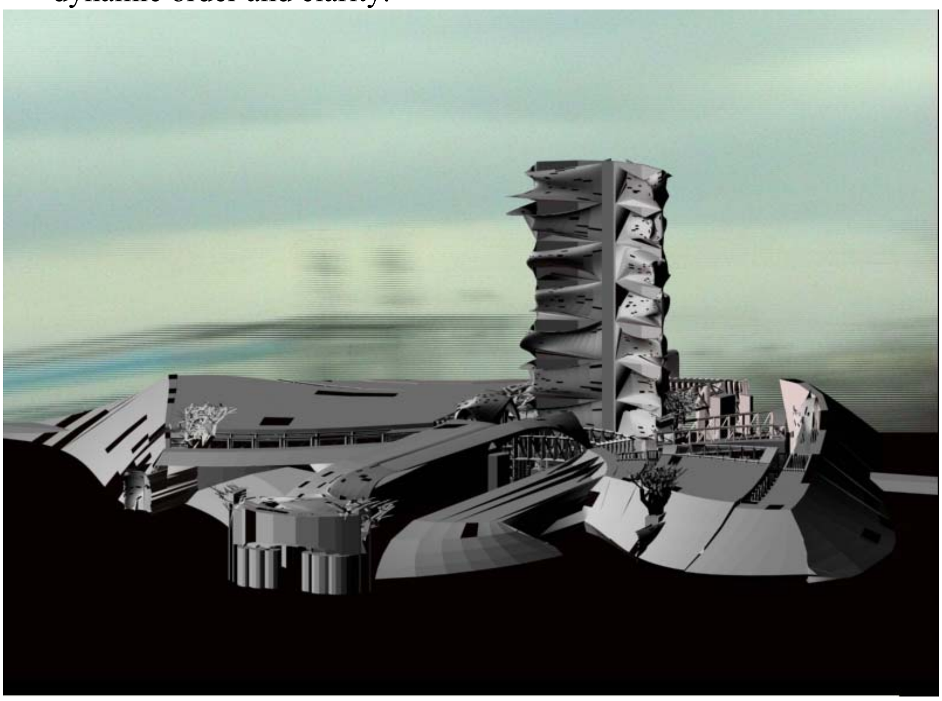
B. Construction of whole codes **of transformation** that represents the identity of a city through operational tools of emulation and simulation of the existing executable dynamics.

C. Construction of a **paradigm of control** of complexity that represents, in the city’s evolutionary dynamics, the structure of relationships subtended in the system of the city, and that fit, at various scales, the same codes. This paradigm becomes the operational tool to manage connections, contaminations and mutual conditionings among the dynamics of growth of the manifold events that transform the city.
D. Identification of **bifurcations** in the complex system representing the city and that determines the **plurality of possible identities** in the various districts of the same city. These manifold identities represent possible scenarios belonging to same species, to same urban identity. Urban identity, in fact, is such if it succeeds in generating different individuals of the same species, quarters and places that, also in their oneness, represent different evolutionary possibilities of the same city.

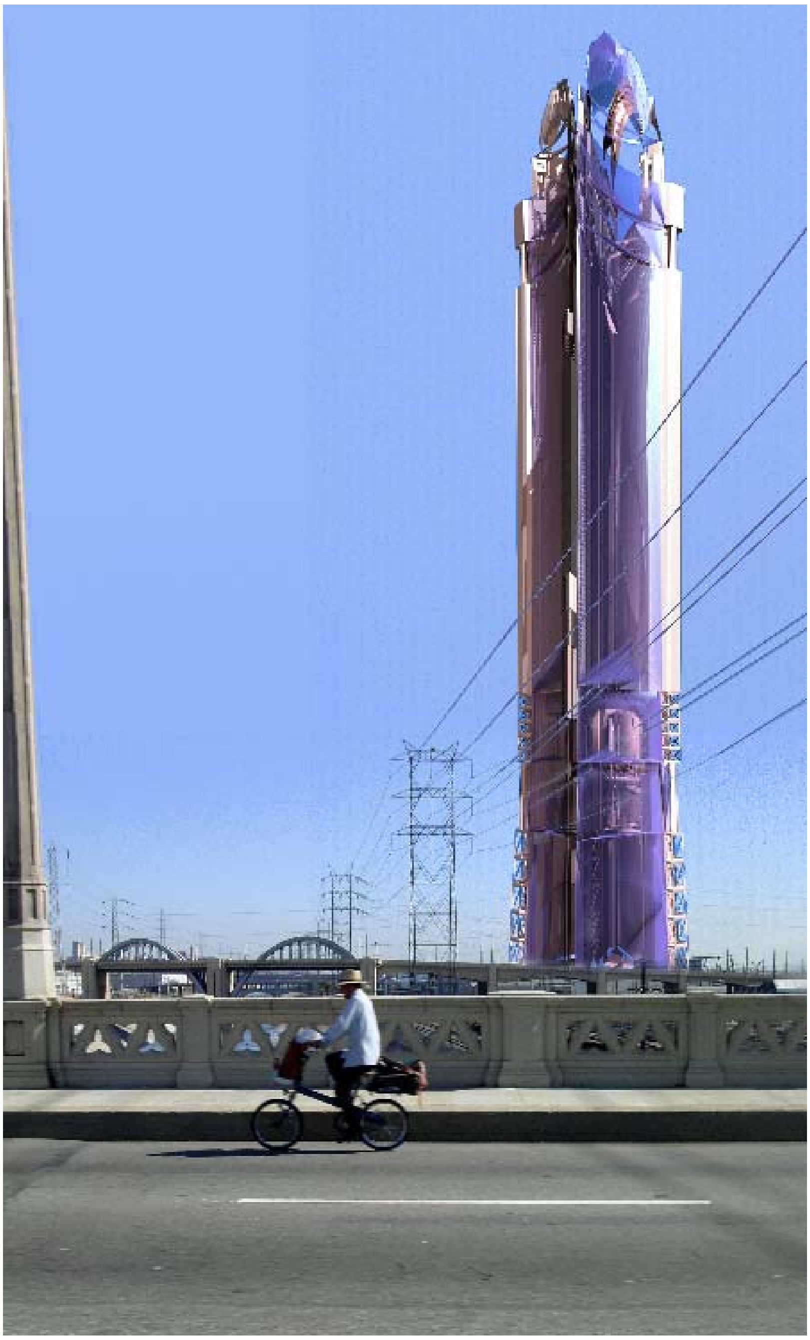


A generated sequence of two different “quarters identity” and their relationship.

E. Identify and design the role of **possible exceptions** as incoming engine for increasing dynamic order and clarity.



Semi-public semi-private space: commercial center, entertainments, private offices and residences, a city inside the city.



Los Angeles, a skyscraper as exception that enhances the town identity

The result is enthusiastic: the city grows following its own vocations and each incoming need becomes occasion for an increase of quality, identity and uniqueness of the city.

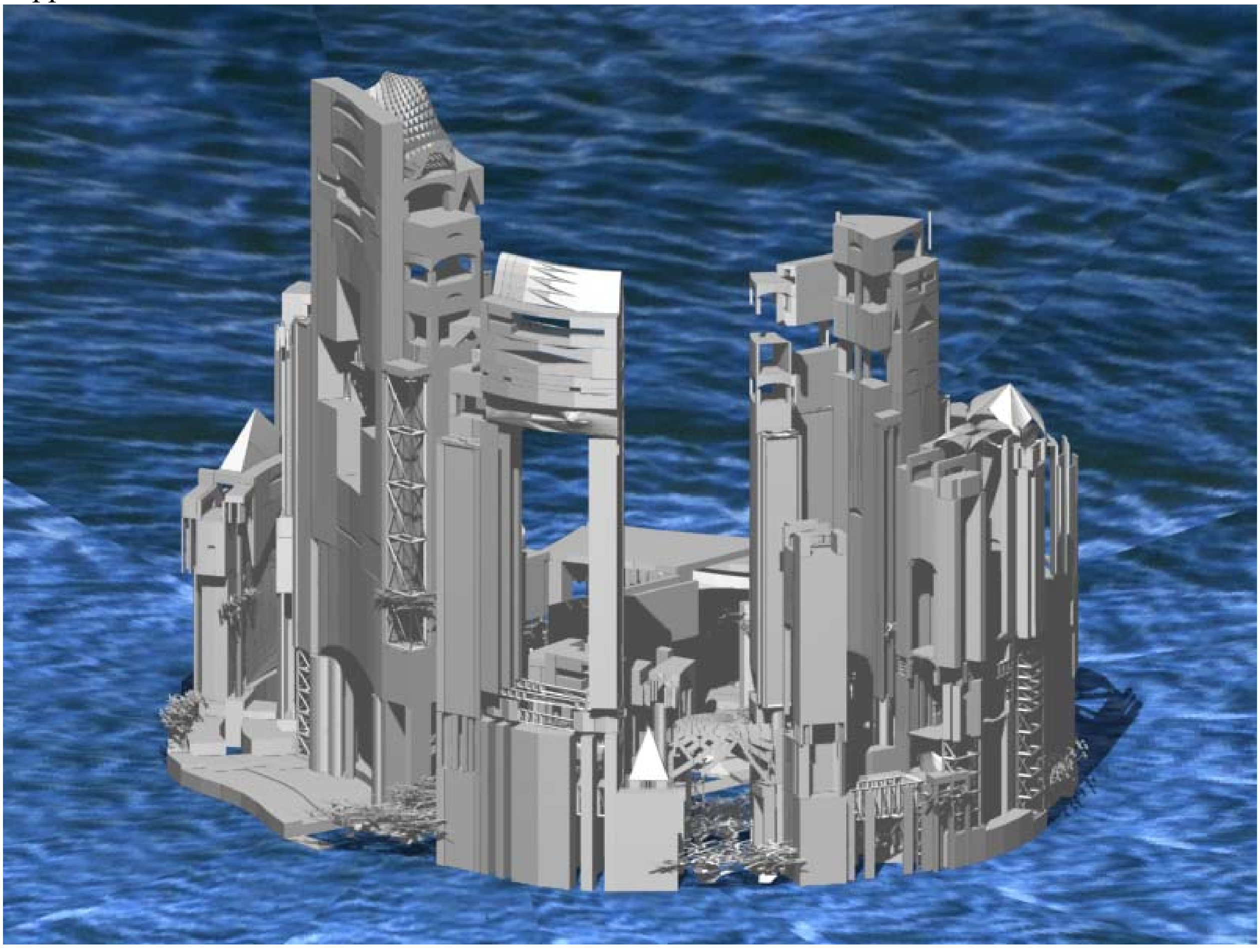
10. Structure and use of Generative City Projects

Building a Generative Project is putting together:

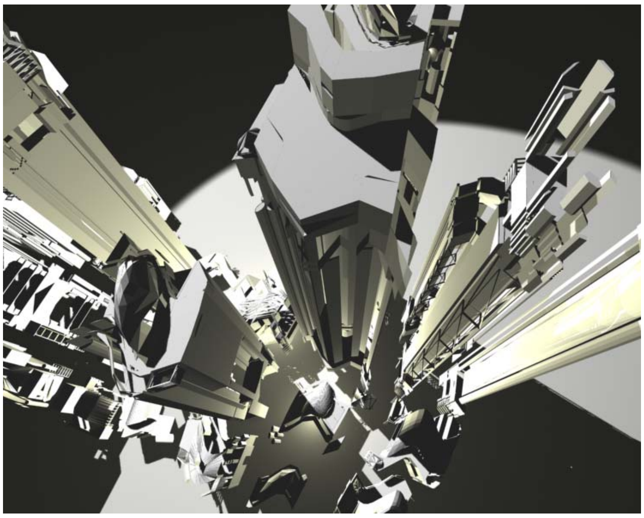
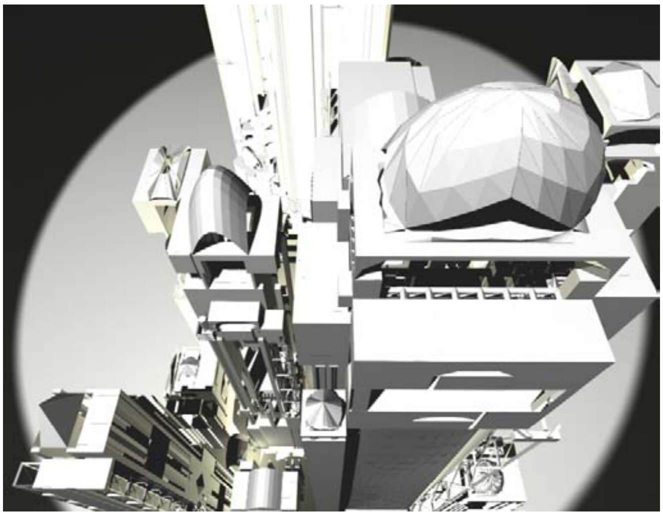
1. **The paradigm that is the plan that defines relationships and structure of complexity;**
2. **The rules of transformation**, the algorithms that explain and design how the present can evolve through the future.

A generative code with these elements, paradigm and rules of transformation, can become, in a progressive increase of complexity, an **executable meta-project** that identifies the character, the recognizability and the communicative clarity of every possible event of city's development. If we

use it, we can generate an endless sequence of incoming town shapes and city's scenarios, all different and unpredictable but all belonging and representing one of the possible result of the same city identity.
This is due to the fact that algorithms are logical structures of representations of transformations that can be operated with manifold and different objects and on different occasions. Paradigm and algorithms of transformation define in fact "how" to operate and not "what" to do or to choose.
The interaction between citizens peculiar needs and city evolutionary project is made possible by the fact that logics, roles and relationships present in the generative project are not simplified and are in progress.
The structure of the functional needs of each inhabitant finds, in this increasing complexity and in the potentiality of functional performances, a wide space to express itself through the paradigmatic interpretation, also multiple, of the possible evolutions.
At the same time the more the paradigm consolidates, the more the occasions grows to apply the code of harmony, as in nature.
In other terms we can affirm **that the more the requirements of the citizen are complex and "impossible", the more the potentialities of the generative code are made operational, and therefore doesn't remain unexpressed**. And consequently if the control of the code, taking advantages of the occasion for specific requirements, work on all levels, from the global to the detail, it increases the communicative clarity, the identity and the quality of the city. (C. Soddu, Generative Art Conference, 2000)
Requests and new needs are occasions and not constrains. This is the peculiarity of Generative approach.



Generated City using Asian Identity transforming codes, (2002)

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Instance and System: a Figure and its 2^{18} Variations

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Abstract

From the structural characteristics of an existing figure - a graphical logo – a plausible solution space of related figures is constructed, which contains all other figures, which may be generated by systematically exploiting the structural characteristics of the input figure. The constructed space of figures can be understood to represent the solution space for the design of the logo. A designer, proceeding systematically by following some generative set of rules would have to construct this solution space at least to the point of a decision, if not entirely. In the presented experiment, this "solution space" will be exhausted completely and the resulting images (there are 2^{18} will be outputted graphically. Questions will be asked concerning the design process, the generative rules, and the selection of the *one instance* representing a solution. The presented results are to be seen as "work in progress".

Constructing and inspecting solution spaces

We regard here generative processes in designing and mean by that, processes, procedures, algorithms etc., which produce "designs". There are examples of generative processes in architecture in literature in music in design; in the fine arts and in a number of other areas. Many of them are represented at this conference [1]. Frequently (but not necessarily) such generative processes are based on very general and universally applicable rule systems that are not specific to the discipline they may serve (examples are the rules of logic or those of combinatorial mathematics). The existence of such "universally" applicable rules also brought out "universally" applicable methods for the treatment of any kind of problem. A well-known example is the method of morphological analysis suggested by Zwicky [2], which applies combinatorial rules to a structured matrix of parameters

Common to all these efforts is to find rule systems, which, when applied will produce solutions / alternatives fulfilling, more or less, the requirements of a set task. One imagines a solution space which we do not know yet but in which the searched for solutions already exist, however at unknown coordinates. They are made visible by a process of generative steps, which send the designer on a journey through the solution space, which ends at a discrete point ("the journey ends on a station". The rules for the generative process are instrumental rules, which actually lead in a finite number of steps to a defined point in the solution space. Thus, the rules must contain a stopping rule. In mathematics such procedural systems are known as algorithms. The imagination of an ordered solution space is useful, because it presupposes that the solutions contained in it possess a certain structure. If solutions are close to each other, they have similar properties. The differences become larger, the further apart from each other they are. However, all solutions are related structurally. The variations are controlled by a set of known parameters, which are manipulated through the rules. This demands they are defined (accepted, selected, have been found, designed, etc.). With the generative approach to design the attention of designing is on the structural characteristics of a problem and on the manipulating rules. Each produced solution represents a valid instance from the system of all solutions conceivable. Depending upon the size of the solution space one can pursue two strategies:

(1) with a large solution space (and most problems require large solution spaces) one can:
- generate *one* solution and judge it immediately;
- generate small sets of solutions at a time, judge each one or compare them to find the "best one" in the set.

The focus of proceeding is here on the single instance, the unique piece, and if necessary on a small number. One can take the "first best" solution, or somehow produce a number of solutions, or inspect the solution space using any sort of criteria. This strategy is similar to the traditional process of designing: one tries to find a solution somehow and develops it, criticizing, changing, improving. Rather unusual (for good reasons) in the eyes of traditional designing is:

(2) the complete and systematic exhaustion of the entire solution space.

It is in principle impossible with real tasks of design to pursue this strategy (rationality dilemma of design) and it is not advisable for pragmatic reasons even with "small" problems (as we will see) the number of solutions residing in a solution space is very large, so large that we can not examine them all. Indeed, if not restrained artificially and with proper measures, the solution space to any design problem is of infinite magnitude. It is exactly the measures of restraining we apply which will determine the strategy which is open for the generative process. This, of course also holds for any other approach to design, but the explicit search and formulation of a generative rule forces consistently to focus on structure. The benefit is we can be "certain" no "good" solution will escape our attention. Normally, the designer is far away from such a position and applies heuristic methods to meet uncertainty. Design is afflicted in principle with such uncertainties.

For the strategy under (2) there are interesting "cases" in literature: in the description of the "academy of Laputa" in Gulliver's Travels by Jonathan Swift [3], Gulliver is confronted with a "…project on the improvement of speculative knowledge…" where "…even the most uneducated person at a reasonable charge and with some physical labour can write books in philosophy, poetry, politics, law, mathematics and theology, without the least assistance from genius or learning". The "Library of Babel" of Jorge Luis Borges [4], is a further example from literature. Somewhat absurd are both, because most of the generative results produced turn out to be nonsense and obviously our capacity is not fitted to handle such tremendous number of possible events. We can interpret the machine in the academy of Laputa as a monitor screen on which each pixel can accept a certain range of values. The output of this system will then be the whole of all representable texts and pictures.

A figure and its variations

For experimental considerations, despite all objections, we now want to design a case of complete exhaustion of a solution space. For an already existing design, a logo [5], designed by the office of Graphic Designers Stankowski + Duschek, (see Fig.1), a solution space will be designed containing all related instances, following the structural properties of the input figure.

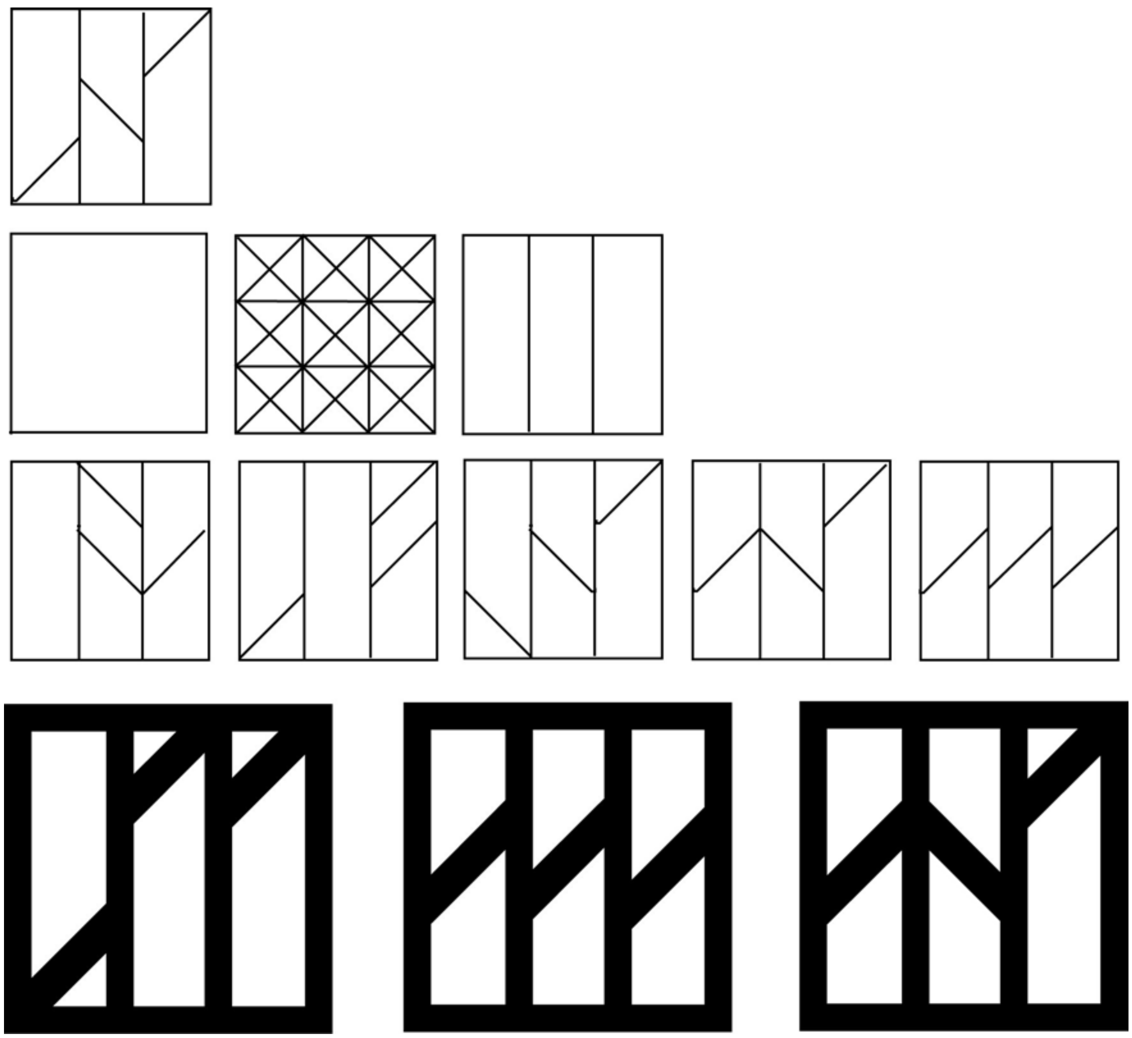

Figure 1
Top: Original Fig.
Row2: Structural System
Row3: Examples using 3 strokes
Row 4: Enhanced

We strictly follow the matrix of these structural properties and only use as variational parameters the short strokes located in defined positions. It seems they represent a substantial characteristic of this logo. Some of the variations are shown in Fig: 2, Fig. 3 is a collection of all possible figures using 3 strokes only (like the initial figure). The structural "system", which defines the logo and all its variations, is a square that is subdivided into nine smaller squares (see Fig.1). In order to construct the solution space to which the figure and its variations belong, we analyse the structural system of the figure and we select the following list of parameters:

geometry of figure: ………………………………. square
structure of matrix: ………………………………. orthogonal
number of cells vertical / horizontal: …………….. 3 / 3
number of stokes per cell: ………………………… 2
subdivision: ………………………………………. two vertical divisions
positions of strokes (angles): …………………….. 45 degrees, (+/-)
variation in line thickness: ……………………….. none
trimming of edges: ……………………………… sharp, no offset
line type: ………………………………………… straight line
etc.

We can now try to design a solution space for the generation of all figures related to the input figure. There are 2^{18} possible instances, see Fig. 2 for a fraction of them. With a relatively simple program one can draw them all (for which 10 sheets of size A0 are needed if each figure occupies somewhat less than a square centimetre). We imagine a systematically working designer, who, before making a choice, wants to know all of the possible variations and has constructed them. He must now device rules of evaluation (selection, judgement), by which all but one of the instances may be rejected. In a design process we normally assume a limited number of alternatives has been developed by the designer from which the best is selected. Two fundamental problems arise, which are characteristic for all design processes: How does one arrive at a solution space? (generation of variety); and: Which selection (decision) rules to use? (reduction of variety). It is hardly possible to imagine a more dramatic contrast between the procedure of complete exhaustion of a solution space and the traditional way of designing. I do not know, how the logo in Fig.1 was developed, but it is safe to assume, the designer did not survey the entire solution space suggested by the structural system, which of course was chosen quite deliberately.
Questions that arise: How would one have to change the generative rules, in order to produce few "useless" solutions? Which changes in the structural system would open further "meaningful" solution spaces? With respect to the suggested figure, are there still figures remaining in the constructed solution space which would be classified by an expert as "better"? Some examples to changes in the structural properties of the initial figure are listed in Fig. 4, where each entry is suggesting an own and differently structured solution space compared with the described one.

Could we formulate guiding statements, agreeable for the majority of the design community, to control the generative process? For the figure under consideration here, some candidates for such statements may be:
- simplicity is good
- a diagonal from bottom left to top right is dynamic, optimistic
- order is preferable over disorder
- geometry generates order
- etc.

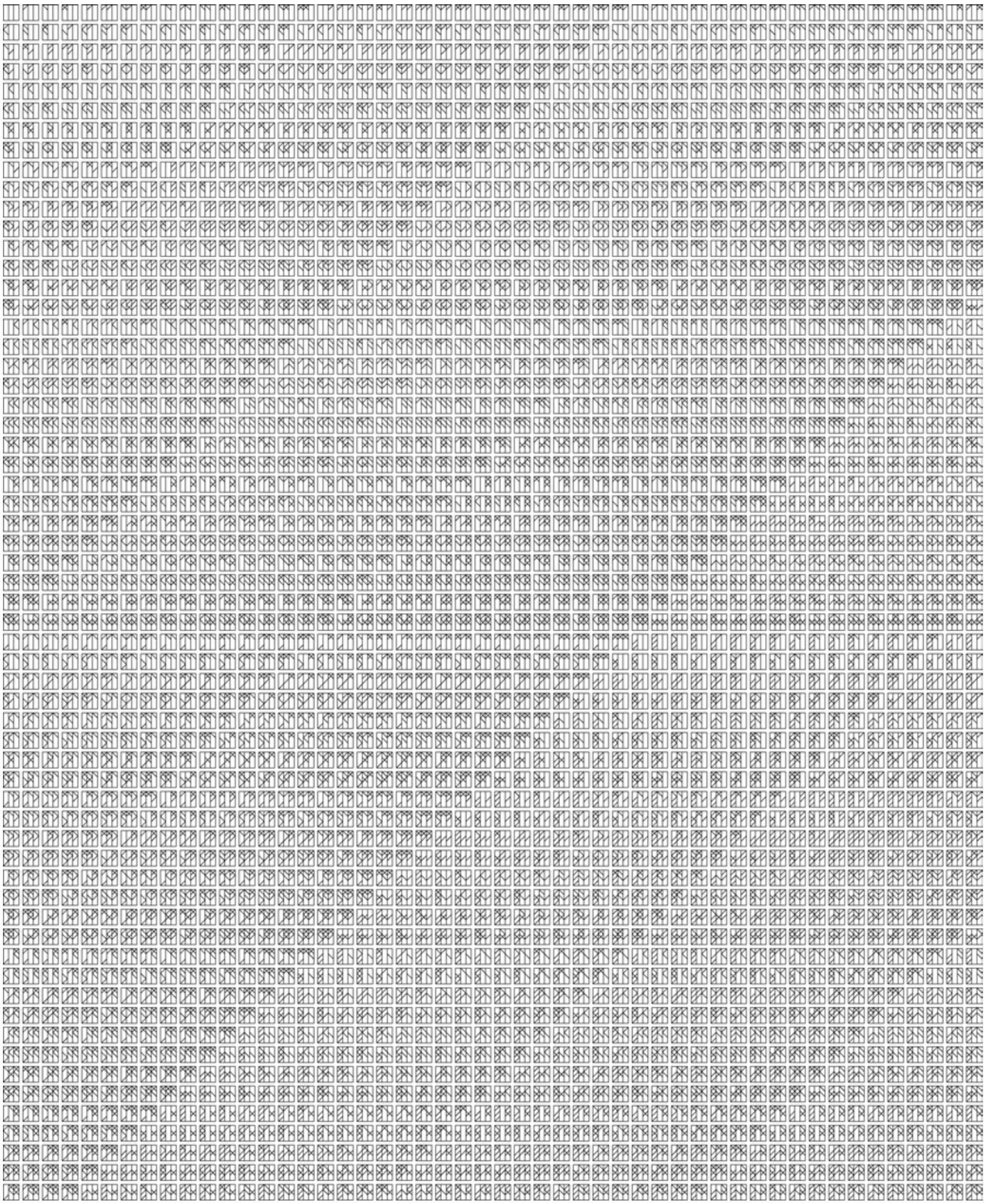

Fig. 2
Fraction of the solution space for „logo“

If we obey such rules, they can provide constraints in generative process like:

- strokes in a few positions only

- no crossing of strokes
- combine two diagonal strokes of same tilt to a double stroke
- occupy only diagonal squares
- etc.

The value of the approach to completely exhaust a solution space may be questionable. But there is also an aesthetic to the produced results, that is quite unique.

Fig. 3
All figures out of 2^{18}, which occupy 3 positions

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Generative and Evolutionary Techniques for Building Envelope Design

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Abstract:

The authors have been involved in the use of generative techniques for building envelope design since 1968 and the use of genetic algorithms since 1990. Recent work has focused on incorporating optimisation functions into form generating processes in order for new forms responding to varied design environments to be created and determined. This paper will summarise the authors' previous work in this field and explain the theory behind this approach, and illustrate recent developments. While the initial implementation of a new building envelope design system is reported in more details in a related paper at this conference, this paper outlines its main features and points out the direction at which it is to be fully developed and further improved.

1. Introduction

At the first Generative Art conference in Milan in 1998 we presented a paper entitled "Macrogenesis: Generative Design at the Urban Scale" [25]. That was a reflective paper indicating key points in the authors' previous involvement in generative design. Selected work was summarised in a series of snapshots of key developments. The then most recent evolutionary work was explained more fully including the "Groningen Experiment" which applied generative ideas to an interactive city planning model for Groningen that enabled citizen interaction with a generative model. The paper concluded by explaining that the whole generative design project had been relocated in a newly formed Design Technology Research Centre (DTRC) in the School of Design at the Hong Kong Polytechnic University where the work was being expanded into the realm of industrial design and graphics. Subsequent papers at GA 1999, 2000 and 2001 presented work from the newly formed centre including [26, 27, 28, 29, 30, 31]. Five papers of recent work are to be presented by the DTRC researchers at GA 2002.

This paper serves as an introduction and overview and starts by restating the original premises of this research. In particular it introduces the generative and evolutionary techniques for building envelope design. One of the recent investigations is the integration of optimisation functions with the form generating processes in order for new forms responding to varied design environments to be created and determined through a series of complex mathematic transformations. In this new investigation, we combine a 3D solid modelling system kernel with a new partial ordering system based on an abstract optimisation technique derived from the theory of non-linear analysis. This approach provided great potential for the development of applications in which the construction and manipulation of complex 3D forms including 3D solid models are incorporated in a knowledge-based and automatic process of generative design. Whilst a related paper by [38] at this conference gives more information about the implementation of the system and the computational techniques employed, this paper presents our overall research in this area and highlights the theoretical issues that have to be addressed in order to develop an intelligent system for building envelope design.

2. Generative and Evolutionary Design

Generative and Evolutionary Design involves using the virtual space of the computer in a manner analogous to evolutionary processes in nature. Whilst the techniques described can be achieved with relatively simple design problems such as yacht design, architectural problems still require computing power in excess of what is yet readily available and are thus only on the cusp of being realisable. This theory is elucidated fully in the author's book, "An Evolutionary Architecture" [1].

In an attempt to achieve in the built environment the symbiotic behaviour and metabolic balance that are characteristic of the natural environment, it proposed the evolutionary model of nature as the generating process for architectural form. The profligate prototyping and awesome creative power of natural evolution are emulated by generating virtual architectural models, which respond to changing environments. Successful developments are encouraged and evolved. Architecture is considered as a form of artificial life, subject, like the natural world, to principles of morphogenesis, genetic coding, replication and selection.

Architectural concepts are expressed as generative rules so that their evolution and development can be accelerated and tested by the use of computer models. Concepts are described in a genetic language that produces a code script of instructions for form-generation. Computer models are used to simulate the development of prototypical forms that are then evaluated on the basis of their performance in a simulated environment. Very large numbers of evolutionary steps can be generated in a short space of time and the emergent forms are often unexpected.

These techniques had previously been limited to easily quantified engineering problems. Only now is it becoming feasible to apply them to the complex problems associated with our built environment. To achieve this it is necessary to consider how structural form can be coded for the utilisation of genetic algorithms, how ill-defined and conflicting criteria can be described, how these criteria operate for selection, and how the morphological and metabolic processes are adapted for the interaction of built form and its environment. Once these issues are resolved, the computer can be used not only as an aid to design in the usual sense, but also as an evolutionary accelerator and a generative force [2].

The evolutionary model requires that a design concept be described in a genetic code. The code is then mutated and developed in a computer program into a series of models in response to a simulated environment. The models are then evaluated in the simulated environment and the code of successful models is selected. The selected code is then used to reiterate the cycle until a particular stage of development is selected for prototyping in the real world.

In order to create a genetic description, it is first necessary to develop a design concept in a generative manner capable of being expressed in a variety of forms in response to different environments. This is a manner in which many designers already work in the sense that they have a personal set of strategies that they adapt to particular design circumstances. This strategy is often very pronounced and consistent to the point where a designer's work is instantly recognised.

3. **Flashbacks**

The 1998 paper then presented 6 flash backs starting by describing the start of this work in the late 60s with the beginnings of a search for an alternative design paradigm the Architectural Association in London in 1969. It was proposed that an increase in choice could be achieved by emulation of the processes of evolution and genetics, which produced diversity in nature. The project introduced the idea of genetically coded building descriptions and the idea of user interaction in the design process and subsequent reorganisation of the building in use. The genetic code of the building was manipulated in a primitive computer model. Later at Cambridge University access to computer power and software expertise allowed this concept to be turned into a working demonstration. [3, 4]

This research subsequently moved to the University of Ulster and then back to the Architectural Association in 1989. One example from this period is included here as a reference. In 1995 a dynamically evolving model for an exhibition in London and an Internet experiment was developed and implemented.

The model was organised by using a multiple hierarchical approach and a data structure which is recursively self similar. The simulated environment in which evaluation takes place was modelled in exactly the same terms as the evolving structures. The environment and the structure not only evolve in the same data space, but could co-evolve. Moreover competitive structures could also evolve in the same space. Environment in this case included user response and was modelled with virtual societies. The environment had a significant effect on the development of the concept using a genetic design language. Genetic algorithms were used to perform the selection and normal crossover and mutation were used to breed the populations.

The model consisted of an endless array of data points, which collectively constitute a data space. Each point in the data space was intelligent in the sense that it knew where it was and why it is there and it had a clear awareness of the spatial relationship of its neighbours. The laws of symmetry and symmetry breaking were used to control the development of the model from the genetic code. Information flow through the model took the form of logic fields. Externalisation of this data structure was process driven by modelling the process of form generation rather than the forms themselves.

The model was based on the sequential evolution of a family of cellular structures in an environment. Each cellular structure began development from a single cell inheriting genetic information from its ancestors and from a central gene pool. Each cell in a cellular structure contained the same chromosomes, which make up the genetic code. The cells divide and multiply based on the genetic code script and the environment with each new cell containing the same genetic information. The development process of each member of the family consists of three parts - cellular growth, materialisation and the genetic search landscape. A genetic algorithm is used to ensure that future generations of the model learn from the previous ones as well as provide for biodiversity during the evolutionary process.

The data structure of the model was based on a universal state space or isospatial model where each cell in the world has a maximum of 12 equidistant neighbours and can exist in one of 4096 states, the state of a cell being determined by the number and spatial arrangement of it's neighbours.

The local environment of a cell can thus be coded in a 12 bit binary string. The growth and development of the cellular structure is controlled by chromosomes.

Chromosomes are generated either by being sent in by any remote user, an active site or as a function of selection, crossover and mutation within cellular activity and are maintained in a main chromosomal pool. The physical environment determines which part of the main chromosome pool becomes dominant. The local environment of each cell then determines which part of the genetic code is switched on. The cell then multiplies and divides in accordance with that genetic code.

As cellular division takes place, unstable cells are generated. In the next generation this leftover material creates a space of exclusion within the cellular space. This space of exclusion interacts with the physical environment to create a materialisation of the model. Boundary layers are identified in the unstable cells as part of their state information and an optimised surface is generated to skin the structure. This material continues to exist throughout the evolution of the model and will initially affect the cellular growth of future generations.

The selection criteria in the model was not programmed but was an emergent property of the evolution of the model itself. A genetic search landscape was generated for each member graphically representing the evolving selection criteria within the model based on the relationship between the chromosomes, cellular structure and the environment over time. Form, or the logic of form, emerged as a result of travelling through this search space.

Once chromosomal stability had been achieved, the parent cellular activity was terminated. The final cellular structure, the materialisation and the genetic search space are posted out. A daughter cellular activity is then initiated from a single cell. The fittest chromosomes from the parent generation are bred using selection, crossover and mutation and combined with the new list of dominant chromosomes from the main chromosome pool to form a new chromosomes set for the daughter generation. The development process is then repeated for the daughter generation [9, 10, 11]

In January 1995 we constructed An Evolutionary Architecture [12] exhibition for the Architectural Association Gallery in London. The centrepiece to the exhibition, The Interactivator [13, 14], was an evolving environment, which was planned to respond to both interaction from the exhibition visitors and the atmosphere in the exhibition space. Visitors were to interact by proposing genetic information, which would influence the evolution of the model. Sensors in the exhibition space also affected the evolution of the model with data on temperature, humidity, noise, smoke and so forth. We extended this concept to allow co-operation on the Internet in three ways: First, by using the Internet to allow virtual visitors to input genetic information to the model just like actual visitors. Second, by allowing the program of the model to be downloaded to remote sites so that it replicated itself and each replication took on a divergent evolutionary path, the results of which could also be fed back to the central model to contribute to the gene pool. And third, by allowing access to the exhibition and the book via a conventional Web site so that the context could be understood and the stages in the development of the evolving model could be observed.

Genetic techniques for design model inner logic, rather than external form, and the exhibition afforded a glimpse of a future architecture as yet evolving only in the imagination of a computer.

Virtual visitors could view the current state of the model and receive an explanation, or they could participate by providing genetic or environmental information. For real enthusiasts, copies of the software were available for downloading. Feedback from remote copies of the software also affected the source model.

In the first two weeks after the launch of the model it evolved four family members based on the chromosomes received and those bred internally, each member achieving chromosomal stability in about 120 generations. Though it is impossible to predict the nature of the model, or its evolving internal logic, there seems to be a pattern emerging towards its selective and hence, evolutionary process.

With the assistance of Ellipsis publishers the virtual version of the exhibition was launched on the Internet in January 1995 [15]. There are some successes and failures to record with this experiment. The central model convincingly demonstrated the principle of evolving a structure under the influence of both public participation and environmental information. But the rate of change was too slow to give any indication of how any individual was affecting it, and the feedback to the net was never properly implemented to show any development. Downloading the model to remote sites revealed all manner of technical problems which meant that biodiversified genetic material never found its way back to the central model. The Ellipsis site was labyrinthine which delighted many visitors but frustrated others who never found how to input genetic information. Overall the experiment attracted a great deal of comment, both on the net and in the press including a feature in Wired [16] and an article in Architectural Design [17]. The Web site enjoyed a large number of visitors.

The 1998 paper finally described an experimental co-operative model for the city of Groningen in northern Holland. It then speculated on how such techniques could be broadened and applied to the possible global co-operative evolution of cities.

We produced a generative computer model, which could mediate in scale, space and time. - In scale between the urban context and the fine grain of the housing typologies. - In space between the existing fabric of Groningen and specific dwelling units. - In time between the life style of the medieval core and the future desires of citizens of the next century.

The Evolutionary Model explained the transition from the past to the present and projected trajectories for future possibilities : A "what if" model for exploring futures and evaluating them.

More specifically we developed a model, which simulated the historical development of Groningen in a dynamic and predictive manner. We searched the local situation for local rules, which would generate self-determining emergent properties for the whole. We looked specifically at the way in which the implications of changing life styles and work patterns could be incorporated into the model. We developed a structure for the model, which was strategically modular (in the sense that say a tree is) without being geometrically constrained to modularity. We embodied all ideas for the housing typologies and the site organisation including environmental influences.

The model was designed using the techniques, which we had developed over the last few years. The structure of the model was new and specifically tailored to the scale and nature Groningen.

Central to the Groningen model was the idea that the computer program inhabits an environment, enters it, reads it, understands its developmental rules and history, grasps its topography, latitude and climate, models its society and economy - and then starts to solicit suggestions and make proposals for possible features.

The model becomes an inhabitant. It maintains a discourse with other, human inhabitants and tries to understand and interpret their desires, aspirations, urges, expectations, and reactions to their existing environment and projected future environments. On the basis of this interaction with the actual inhabitants, the virtual Inhabitor patiently modifies its criteria for evolutionary development and selection, endlessly repeating the process of refining and modelling prototypical futures. As it does so, it occasionally produces experimental genetic mutations or amplifies variety.

The working prototype was demonstrated in Groningen and then in London in June 1996. It was subsequently exhibited at the Architectural Association in July [19]. An interactive map with video input of modelling blocks provided an easy interface to the system. The demonstrations were very favourably received and many valuable comments were recorded. The intention now is to seek further funding for a robust demonstrator system which can be used to test the system with the inhabitants of Groningen. Holland is a café oriented society. The intention is to provide interactive systems in some of the many cafés of the city [20,21,22, 23].

To paraphrase Stafford Beer "The public is conceived as a system, a model of which is contained in the computer. The public supplies minimal information, which the computer then synthesises in the model. This amplifies variety as required to help the public and attenuates variety to help the manager - thereby meeting the requirement of the law of requisite variety for each of them".

Interaction with the Inhabitor is achieved via the Enabler, which has connections to an interactive map (input desire lines etc) and an active output model.

We feel that this experiment went some way to realise, through the medium of modern digital technology, the preoccupation of Patrick Geddes that the ordinary citizen should have a vision and a comprehension of the possibilities of his own city. This experiment addresses the need for and value of "citizen participation" in town planning. It also demonstrates the need for a Civic Exhibition and a permanent centre for Civic Studies in every town - an "Outlook Tower". We are proposing that the cafes of Groningen should be the Outlook Towers of the future.

4. Post 1996 – Developments in Hong Kong

Generative and evolutionary design techniques are at the centre of the systems and environments being developed by the authors at the Design Technology Research Centre in the School of Design of the Hong Kong Polytechnic University. The DTRC was established in 1996 by Professor John Frazer and was formally validated by the Hong Kong Polytechnic University in 2000. A new and generic computational model of the design and making process consisting of a unified data structure of space, information and knowledge, an alternative computer enhanced design process, and an environment of design that relocates the user, the designer and the tool. A wide range of topics in this area have been investigated in order to define the primitives, rules, constraints, evaluation criteria and environments in order to make the best use of generative and evolutionary computational techniques including mainly genetic algorithms, neural networks, and machine learning techniques.

In order to develop a unified data structure of space, information and knowledge for intelligent design support, in an extension to conceptual seeding, we have further developed the representational schemes, which we call rudiments and formatives. In our new application domain of product design, a rudiment defines a set of the functional component classes with related design knowledge about their geometric and feature attributes. Rudiments are defined in the context of an evolving environment is which they may have the potential of being selected and further developed. And in particular they must be combined or structured in such a way in which genetic algorithms or other form of generative programming can be used to derive a new data structure we termed the formative. A formative encapsulates rudiments with their relationships in a meaningful design process, as well as the product configuration rules to be used during further design development stage. A rudiment is static in the sense that it is built in advance, whilst a formative is dynamic because it requires user's interaction to formulate a design problem space, which is loosely constrained by the instantiation of rudiments. This design problem space defines geometric as well as aesthetic and ergonomic constraints, which can be subsequently explored by genetic algorithms through a product component hierarchy. Design knowledge such as the strategies of Design for Manufacturability (DFM) can be encoded into the generative product design support system as rudiment definitions or selection criteria. A recently completed PhD thesis successfully demonstrated the feasibility of rudiments and formatives in the application of abstractive mobile phone shape design [34].

The second system that has been developed [36] deals with the complexity and collaborative nature of design in the context of using generative and evolutionary techniques in design in a generic manner in order to provide a system for exploring the complexity of design problems through a hierarchical representation of evolving elements and evolving mechanisms. This system attempts to develop a computational framework that supports design exploration at different levels of abstractions that are hierarchically represented and processed. A hierarchical evolutionary framework has been implemented, which consists of networked elements evolving and interacting with others according to their "evolutionary mechanisms". Each network element can be evolved to become next element down in the hierarchy with the evolutionary mechanism associated with it. When applying this hierarchical evolutionary framework to a design problem, the hierarchical network represents the whole design task or process whilst each element in the network represents an evolving sub-solution to the whole problem at a specific abstract level. Users and designers can interactively manipulate design objects at different levels. Genetic algorithms and cellular automata are used as the main evolutionary mechanisms that can be linked to any element in the hierarchy. This framework is currently being explored with experiments in both 2D and 3D design. In particular, it is being used to develop a system supporting Chinese font design, in which domain, the design of each stoke in a Chinese character, and the design of a coherent character with aesthetic and spatial integrity may be represented or processed in a hierarchical framework..

The third system is based on an alternative approach to the design of buildings. In this approach, the development of generative and evolutionary system in building design consists of three parts: (1) a method of designing that relies on an evolutionary software environment, (2) a computational strategy that describes how the evolutionary software environment might be implemented, and (3) a software development kit that provides software components that can be assembled to create customised evolutionary design environments.

In this system, the proposed design method splits the process of designing a building into two tasks. These two tasks are liked to each other via an entity referred to as a design schema. The first design task is to define the design schema. The use of a schema is a common tactic in design. In most cases, a design is not a one-off, but is instead one of a family of designs. This family of designs might be represented by a design schema that encompasses the variations within the family. The design schema is an idea that encapsulates the identifiable and recognisable character of the designs. The second design task is to instantiate a particular design form the schema using the evolutionary software environment. The proposed method therefore relies on a software environment for design that combines the design schema tactic with the use of evolutionary algorithms. Evolutionary algorithms are loosely based on the neo-Darwinian model of evolution through natural selection. Such algorithms consist of a cyclical process whereby whole populations of individuals are continuously being generated and manipulated in order to ensure that members of the population gradually evolve and adapt [32].

Other systems developed by the DTRC included a tree representation scheme with which genetic algorithms manipulate directly on tree, and to switch nodes in the tree in crossover and mutation to explore alternative and unexpected design solutions involving 3D products of more than one component [33, 35]. Other research projects in the DTRC are also exploring the possibility of using rudiments and formatives to develop systems for design for environment focusing on the embodiment of green product design [37]. All these projects are centred at the development of a taxonomy of generic forms by adopting methods of morphogenesis in the natural sciences. Using these methods a collection of industrial artefacts can be obtained to establish a taxonomy of form and to construct physical models showing morphogenetic processes, and then to develop virtual models that can be integrated in computer based design support systems.

5. Building Envelope Design System

This paper ends by introducing our latest work on the application of generative and evolutionary techniques for building envelope design.

The creation and exploration of unpredictable and non-repeatable forms with certain ways of controlling their abstractive nature are difficult tasks, especially when the outcomes of the system are not just images but solid models. Most existing CAD systems require detailed geometric specification through sketching and transformational methods in order to generate 3D forms. This presents serious limitations to the generative and creative capability of computer based design support systems. These limitations motivated the development of the new approach to architectural envelope design introduced in this paper. In this approach we combine mathematical functions with 3D solid modelling transformation methods to create abstract but novel forms.

Several difficult issues must be tackled before such a system can be practically used to support building envelope design.

- Computational techniques for creating and improving design alternatives in a goal directed manner,
- Creation and exploration of complex forms from basic but intelligent elements representing and stimulating the process of generating novel design concepts,
- Linear and non-linear algorithms for modifying abstract forms to obtain complex forms through spatial or conceptual transformations, and
- Visualisation and animation of the forms generated in a format compatible with main CAAD or CAID tools and environments.

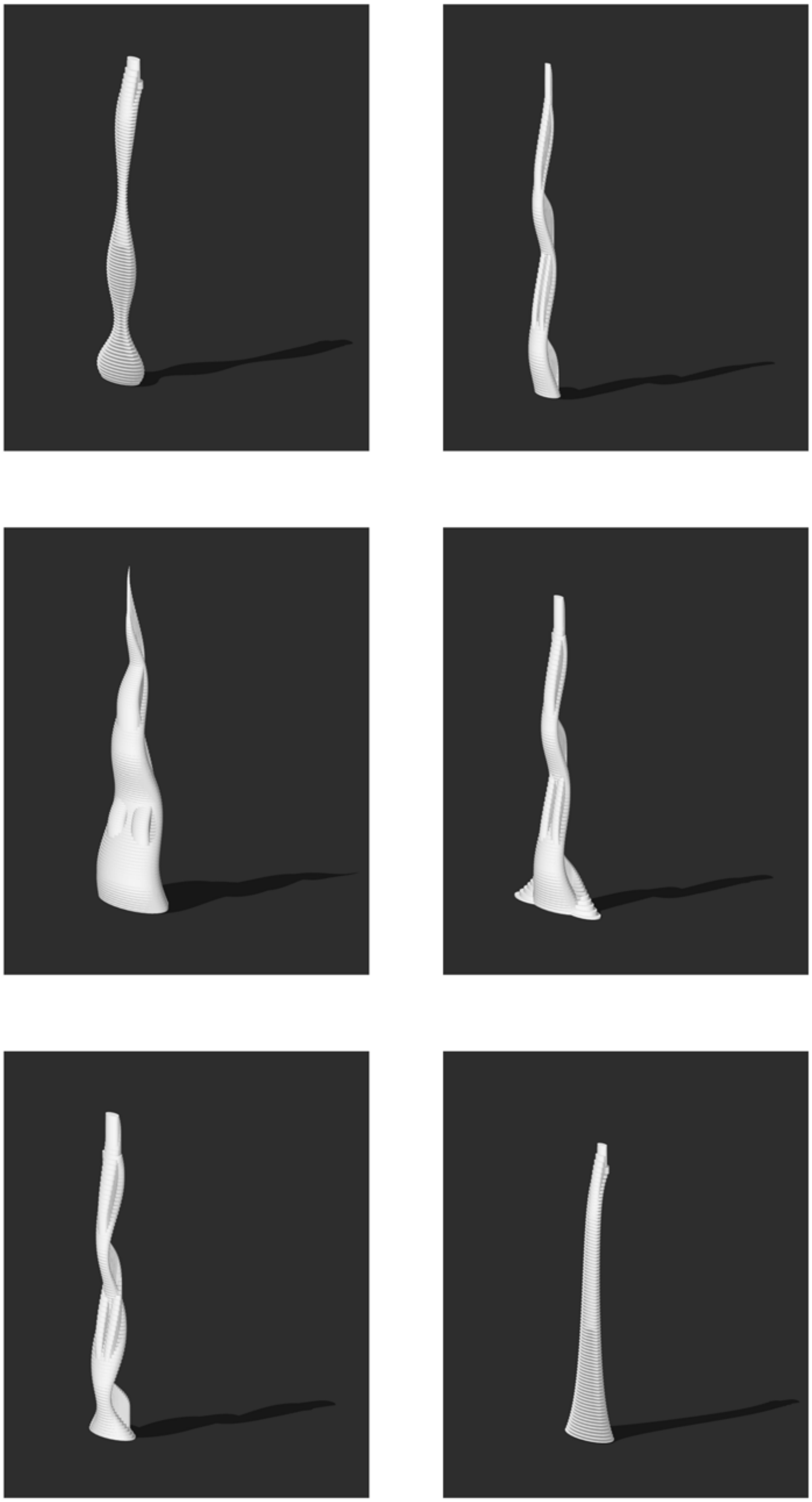

Figure 1. Forms generated by Building Envelope Design System

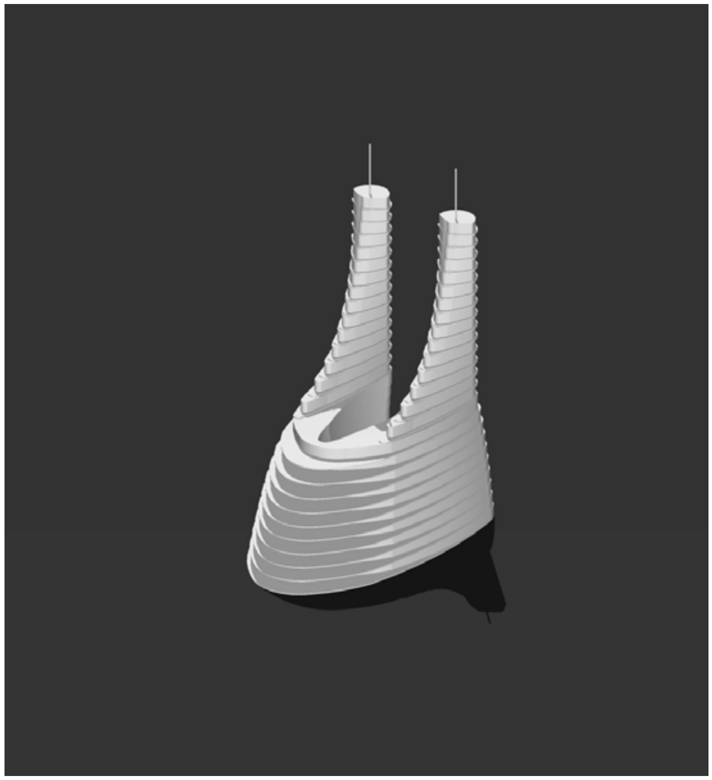

Figure 2. An example of a building envelope generated by the system.

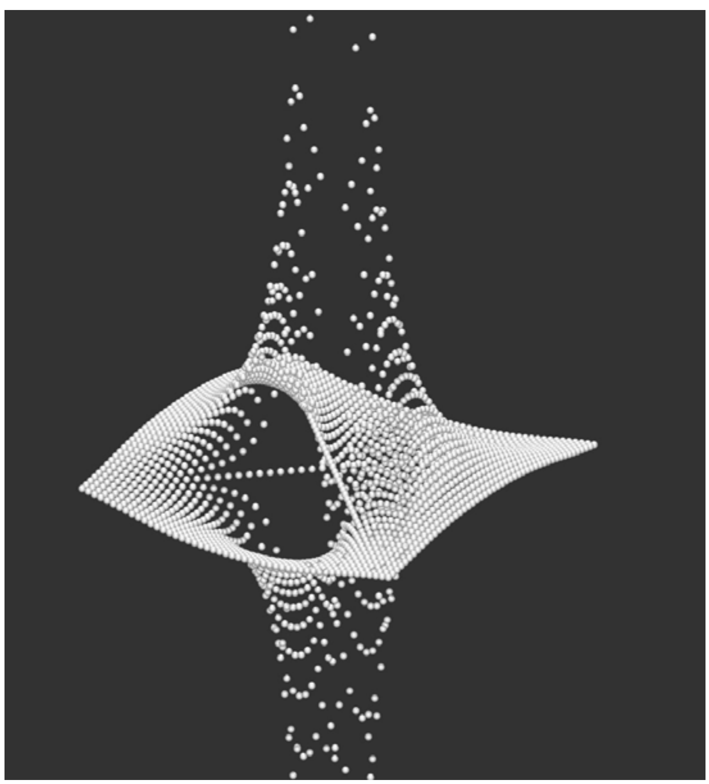

Figure 3. Generative nodes

Our particular concern is the formulation of computational complex form creation process with various generative processes in which genetic algorithms or other automatic computing methods such as partial ordering can be used to increase the novelty and creativity of the system. We decided to develop our system based on 3D solid modelling techniques enhanced with complex mathematic functions. The system kernel is compatible with object-oriented technology and 3D solid modelling and surface modelling standards. The images and rapid prototyping models generated using our system are otherwise impossible to generate by normal CAAD systems, without integrating generative and evolutionary computation techniques with 3D solid modelling techniques.

While the technical and implementation details of this system are described in a related paper by [38], the significant features of this system in relation to our past research and future direction for developing an intelligent system for building envelope design are highlighted here.

ACIS 3D Solid modelling kernel is the core used by major CAD systems including ProEngineer™ and SolidWorks™, With its numerous geometric manipulation and transformation methods for solids and surfaces, it is relatively easy to derive object oriented class definitions for creating architectural envelope models.

In the initial implementation of our building envelope design system, we have built an object library [38] containing 47 object classes derived from basic ACIS 3D solid or wire-frame models. Among these, 17 of them are form (complex solids, surfaces and wire-frames) creation classes whilst others perform transformation, interaction with users, or linking the form creation process with a genetic algorithm. With this domain independent object library, it is easy to develop new and domain specific architectural envelope models. For example, an instance or a number of alternative instances of a solid tower model can be created using an object definition in the library by specifying two mathematical functions, i.e., the centre line and the outline. This object definition can be easily extended to include outer surface profiles or interior details such as colours or textual mapping for the development of more domain specific features. In this library, surface representation (or boundary representation) and constructive solid geometry (CSG) are combined.

We also enhanced a commonly used solid representation called spatial partitioning in order to apply mathematical expressions to the form creation process. This is done by decomposing a complex solid (such as an architectural envelope) into a collection of smaller, adjoining, non-intersecting solids (floors or rooms) that are at a lower primitive level than the original solid (the whole structure of the envelope). A number of variations are used in the decomposition process. These included: cell decomposition, spatial-occupancy enumeration, octrees, and binary space-partitioning trees.

A tower, for example, is generated from many cells and layers. Once the centre line and outline are specified mathematically with a symbolic representation. Dividing the tower into cells and layers is then automatically handled by the system in a way similar to identifying the grids in a finite element analysis system, giving a few control parameters such as number of cells and layers. The interior details or the materials of the textual can be applied to different layers or cells. Once the model is complete, all the individual cells and layers are untied to form a single object, which can then be exported to other CAAD systems for further analysis and modifications. Additional functions and operations we termed mollifying operations are provided by our system to make sure the smooth transition from cells and layers to a united 3D solid model without discontinuity. Before the operation of uniting, any cell or layer in a completed model can be substituted with another model containing more detailed structure but with the same size and shape. After the uniting operation, a model can be used as a cell or a layer to generate more and more complex forms. The recursive transition of a cell or a layer to a model makes it possible to generate very complex forms with same mathematical centre lines and outlines.

In our system, we introduced a new version of genetic algorithm to enhance its generative capability. This is achieved by extending the classical powerful computational techniques based on modern non-linear analysis theory to the natural selection methods for optimisation of GA. This new version of genetic algorithm used the idea of partial ordering in topological spaces. A Zorn Lemma type of iterative procedure is introduced in the genetic algorithm to partially overcome the difficulty in implementing effective natural selection in the evolutionary process. Zorn Lemma is a basic result in partial ordering theory. It is a derivation of a set axiom. This lemma ensures that a maximal point in a certain subset can be obtained provided that it is totally ordered. Based on this lemma, we defined a multi-objective evaluation method, and accordingly, the fitness functions in the genetic algorithms must calculate appropriate information about the individuals, and then use this information to calculate how well each individual satisfies their particular criteria. The total fitness function is a map from each individual to a point in the high-dimensional Euclidean space with or without linear structures. In this space, partial ordering is an effective method to represent relations of points. The definitions and proposition of this theory are described and proved in [38].

Considering the complexity of real architectural envelope design with abstract or specific requirement specifications involving potentially large numbers of variables and constraints, the design problem space will be ambiguous and incomplete, and may never be explicitly quantified at a level comprehensible for the users. The partial ordering theory offers a way for introducing automatic natural selection into the otherwise more open-looped artificial selection process of genetic algorithms, such as those employed and reported in [31, 33, 34, 35]. However, this part of the work is still in the early stage as we write this paper. The issue will be thoroughly investigated in our next step since there is a great potential for the application of these ideas in an architectural context, but so far we have been unable to comprehensively demonstrate the value of this approach with convincing examples. However, it has been clearly demonstrated that our system implemented so far is able to provide powerful generic support for testing novel ideas in a domain specific context with complex forms of astonishing degree. It is obvious that even with the application of our system with simplified examples in architectural envelope design, computing power is being challenged and more intelligent software is needed for creating unexpected sophistication of beautiful architectural forms competitive to those created by human architects.

Whilst our system focuses on generating 3D solids and wire-frames compatible with main stream CAD systems such as MicroStation™ for architectural design or ProEngineer™ for product design or product design, additional rendering and lighting effects can be achieved by converting SAT files of ACIS kernel into other formats including rapid prototyping format (STL).

6. Conclusions

The integration of mathematical function within a 3D solid modelling kernel as the basis of a form generating system, the application of a partial ordering theory combined with natural selection criteria of genetic algorithms in a complex topological space, and the enhanced geometric transformation and repairing operations on complex solid and surface models are the key components of a building envelope design system that has already been implemented. Early testing of the system has shown some interesting and promising results.

Six years on, in the Design Technology Research Centre (DTRC), we are now in a position to develop a full-scale application for architectural envelope design, and indeed for product design as well, with the capability of generating complex and evolving forms that are otherwise hard or impossible to create and manipulate. With the exciting real design and development in Yunnan province in mainland China where potentially over a hundred cities and towns are to be redesigned on the balance of modernisation and preservation of ethnic minority culture and concerns for environmental and ecological protection, we expect to integrate generative exploration and constrained optimisation in large scale applications for which we can use our Global Virtual Design Studio for visualisation and evaluation of architectural envelope design concepts in a more interactive and collaborative manner. Our collaboration with Yunnan Development Centre will provide a unique opportunity for us to further develop and test the system described in this paper and a related paper [38].

Next, we will look at solar geometry or more general environmental concerns to formulate a multi-objective design problem based on partial ordering theory in a more domain dependent context. In the meantime, our other research projects in the DTRC on the taxonomy of generic forms based on morphogenesis, extension to rudiments and formatives in product design applications, and the development of a designer's workstation of the future, will provide further insight on how intelligent design tools can be developed to support designers, based on the principle of generative and evolutionary strategy, computer enhanced process, user centred interfaces, and integrated computational algorithms.

Acknowledgements

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Generative Art: Multi-Modal Meanings

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Abstract

This paper introduces the concept of *multi-modality*, drawing upon recent work in the field of social semiotics [1] in an attempt to theorise how art generated through a variety of media deployed in a variety of modes may be understood through semiotic principles applicable to them all.

Medium is defined as the means of expression (material and other technologies); *mode* is defined as the manner of expression. Case studies from the field of sculpture are illustrated.

Introduction

In the general context of the series of Generative Art conferences held between 1998 and the present, two directions of research appear salient: one concerned with methods of production, in particular the construction of algorithms which generate art and design forms; the other concerned with exploration of suitable areas for the application of such generative tools.

Both of these directions have facilitated exciting and extraordinary contributions to knowledge.

I would like to suggest a third direction in which research may prove beneficial to our common goals. A direction of inquiry into the concept I shall term *reception*: how is art, generated multimodally, received in social context and how is its meaning is negotiated?

The semiotic principles applicable to the analysis of multimodal artworks derive from Ferdinand de Saussure's [2] seminal work theorising the communication process as entailing a series of paradigmatic choices of signs (e.g. visual elements) combined syntagmatically according to the rules of the code shared by sender and receiver. Awareness of the importance of theorising such communication *within a social context* was raised by Mikhail Bakhtin and Pavel Medvedev. [3]

Bakhtin and his circle were proposing a reassessment of Saussure, who had chosen to foreground the structure of language (*langue*) rather than speech (*parole*), and a synchronic analysis of language rather than a diachronic one. Bakhtin re-engaged the poles of these dichotomies, and treated them dialectically – as oppositions between terms which depend upon each other for their meaning. By doing so, he facilitated the study of communication within a *dialogical* context. [4]

Bakhtin and his colleagues effectively resolved the antimony that Saussure's separation of *langue* and *parole* had presented, and thus laid the foundations upon which a *social semiotics* may be constructed. Social semiotics theorises the relationship between codes of communication and the contexts of situation in which they operate. He and Pavel Medvedev asked:

> How, within the unity of the artistic construction, is the direct material presence of the work, its here and now, to be joined with the endless perspectives of its ideological meaning ?…
> What, in fact, is the element which unites the material presence of the work with its meaning ?
>
> We submit that *social evaluation* is the element. [5]

A Model for the Social Evaluation of Art

Four stages are proposed in a model for the production and evaluation of art within a social context

1. *Discourse* is defined here as the realm of socially constructed knowledge in which thinking and debate about artistic production takes place. Art discourse involves a wide range of social contexts: the discourse of art constructed through a populist newspaper seeking sensation, for example, will often adopt a negative manner towards contemporary art practice (*The Turner Prize* in Britain, is usually subject to such negativity), whereas arts discourse formed through critical journals may allow far more flexibility of opinion about the social functions of art to flourish.

   It may be demonstrated that although such discourses afford varying attitudes towards art work, they share in common the semiotic principles upon which all discourse is based: those of selection from the range of registers and modalities through which opinion and debate may be expressed in a variety of media. For example within the discourse of classical sculpture, certain compositional choices to do with balance, harmony, and 'the ideal' may be foregrounded; whereas within the discourse of constructivism, choices to do with fixings, contrasts of scale, texture, and movement may feature.

2. *Conception*, its root the Latin verb *capere* 'to take', is defined as the stage of artistic engagement at which the artist is 'taken with' an initial idea or concept. Such concepts may be explored through a variety of media (from pencils to software packages) in diverse modes (doodling, sketching, modeling). Each of these modes connotes social meanings which may be analysed using semiotic principles common to them all. For example, the semiotic principles articulated through the process of selection from a range of choices to do with geometry systems, scale, format, weight and density of marks, and the analysis of the social connotations, or values, that each choice carries within a specific context.

3. *Inception*, from the same Latin root, may be understood as the stage at which a concept is 'taken up' in production: fully realised in material form or other technological media. The multimodal possibilities of material expression may be analysed through semiotic principles applicable to all media. In sculpture, for example, the system of choices

concerning the textural qualities of the work, (a *system of choices* articulates a full range of possibilities available for selection), systems of choices to do with scale, weight, density, balance, symmetry, stability of materials. All materials and combinations of selections from the available systems have potential to carry connotations of style, social value, and in the case of static sculpture, connotations of speed and movement.

4. *Reception*. This term represents the stage at which the artwork is 'taken in', or received within the public domain. The complexities of media (the means of expression) and modes (the manners and expression) may range from the properties of the display environment and the manner in which its *ambience* is manipulated, to the manner in which the work is publicised and reviewed. Here too, it is argued, there is the possibility of a common means of analysis based upon the recognition that selections have been made from systems of choices.

Case Studies

Two pieces by Western Australian artists were discussed in the conference presentation:
T. L. Robertson by Ken Hannan (Fig. 1). A bronze bust set on a hardwood plinth against a background of marble in the foyer of the Library, Curtin University, W. A.
Loco by Lou Lambert (Fig. 2). A construction of wood and iron, set in natural landscape on the Curtin University campus.

It was demonstrated in discussion that the contrasting modalities of the two pieces were compatible within a discourse of sculpture encompassing the oppositions which define Classicism and Modernism:

T. L. Robertson	Loco
sculptured	constructed
indoors	outdoors
cultural context	natural context
static	dynamic
balanced	unbalanced
symmetrical	asymmetrical
Classical	Modernist

The three modalities of material combination, dress and pose in the *T.L. Robertson* bust all operate simultaneously to uphold the historical values of Classicism (bronze, hardwood and marble), the social values of conservation and formalism (collar, tie, waistcoat and jacket) and intellectual achievement (the head, excluding hands or full figure, and the prominence of the academic gown.) In contrast, the construction adopted for *Loco*, with its large, heavy, rough elements of wood and iron arranged asymmetrically, often interpenetrating each other, and visually off-balance from every angle of view illustrates how effectively the modalities of scale, weight, surface treatment, and composition may all operate simultaneously to visualise powerful dynamic forces out of control ('loco'.)

Such multi-modality at work within the two pieces is extended when the works are received in their contexts of display: The bust, located in the foyer of Curtin University's Library, is an ever-present reminder of the quiet control of the intellect, the rational, the process of learning smoothly elided between one generation and the next by means of the written word. Outside, not far away on the same campus, *Loco* clangs, stamps and charges: industrial, dangerous and loud in a glade of unspoilt nature…

Fig.1

Fig.2

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Figura, aura uniqueness

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1. Exordium

"O look, look in the mirror,

W. H. Auden, 1937

2. Narratio

Objective: to discover Figura as an identity expression in Generative Art**.**

This process can start from **impression** to **emotion.**

Impression*:*

Aqua figuraque

Figura entrò in Acqua / Figura went into Water

E specchiandosi esclamò / And seeing mirrored said

Eureka, non mi dissolvo! / Eureka I don't dissolve!

L'acqua, infastidita / Water irritated

Elargì uno schizzo di rabbia / Handed out an anger splash

Dicendo: " Come non ricordare / Saying: " How can't one remember

L'antica amicizia?/ The ancient friendship?

Dalla pietra levigata dal Tempo/ From Time smoothed stone

Emergesti come una ipotiposi vagitante"./You rose as a wailing hypotyposis.

2.1 Theme

Lookig for *Visionary Ideal*,*Recognizable* sense.

Visionary

2.2.1 Kubla Khan by Coleridge

Or, a Vision in a Dream. A Fragment

…A damsel with a dulcimer

In a vision once I saw:

It was An Abyssinian maid,

and on her dulcimer she played,

Singing of Mount Abora.

Could I revive within me this case "

Her symphony and song,

To such a deep delight 'twould win me,

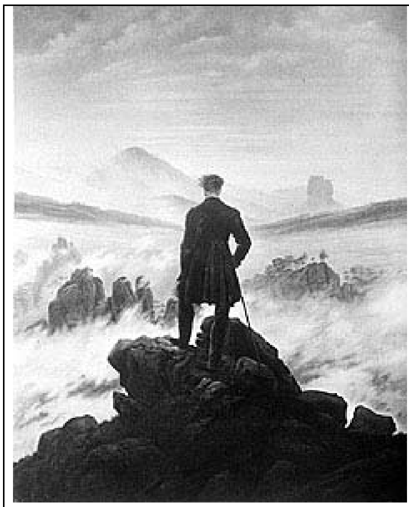
that with music loud and long,

I would build that dome in air…..

2.1.2 Caspar David Friedrich, Wanderer above the sea of fog

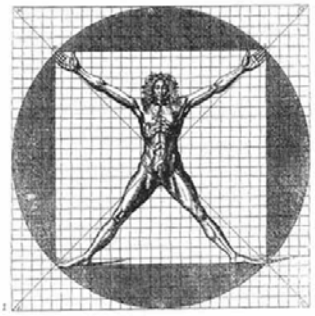
One speculative point of view: ***emotion***

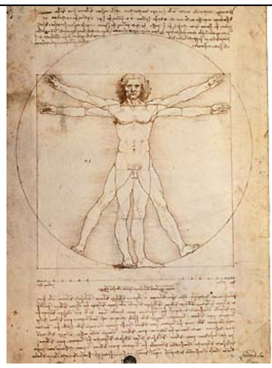
"Close your eyes so you can see the image principally with mind eye. Then take what you have seen in the darkness to the light, so it is reflected on the other people, from outside to inside".



Ideal

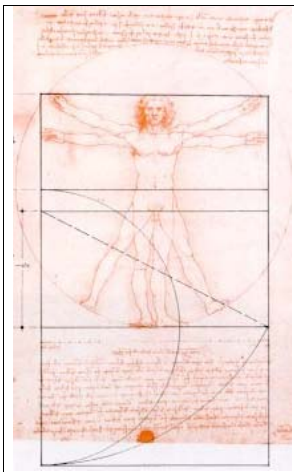
Per traslazione sogno in piedi/In figurative standing I dream

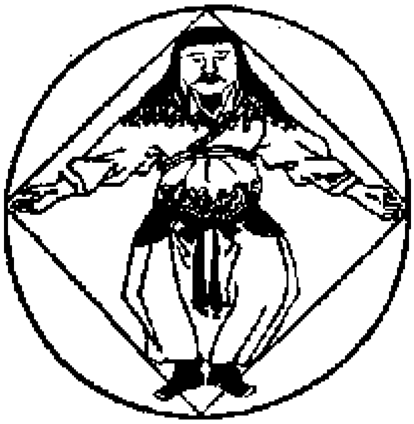




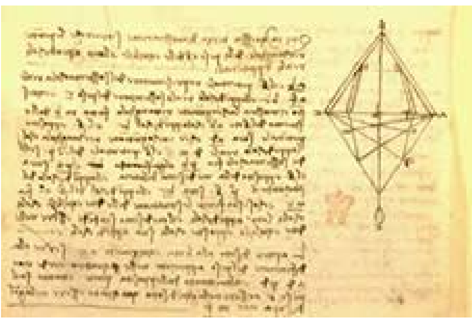
2.2.1 Vitruvio, Homo ad circulum, De Architectura

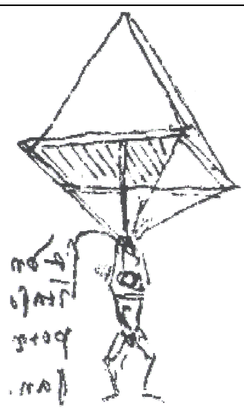
2.2.2 Leonardo, L'Uomo di Vitruvio_"Tanto apre l'omo ne' le braccia quanto è la sua altezza" As man can open his arms as his heightnon





2.2.3 Leonardo notebook, words in the mirror





1-In this notebook the text is in Leonardo's characteristic 'mirror writing', written left-handed and from right to left

2- Leonardo Da Vinci,Codex Atlanticus Folio 381

Recognizable
C'è il sole sull'erba / Sun is on grass
IL tuo passo lento / Your slow walking
Mi indica l'oscurità esplorata / Show me the explored darkness
2.3.1 Idea as a Code. Figura is the coexisting multitude site. Poetic identity

3.1 Divisio

3.1.1 Entimema

"O stand, stand at the window

"Art is not magic, i.e.,a means by which the artist communicates or arouses his feelings in others, but a mirror in which they may become conscious of what their own feelings really are: its proper effect, in fact, is disenchanting"
W. H. Auden,1937

3.1.2 Propositio


Draft for Angel head,Torino, Biblioteca Nazionale

3.1.3 Ratio National Gallery

3.1.4 Ratio Louvre

3.1.5 Ratio 3 Versions

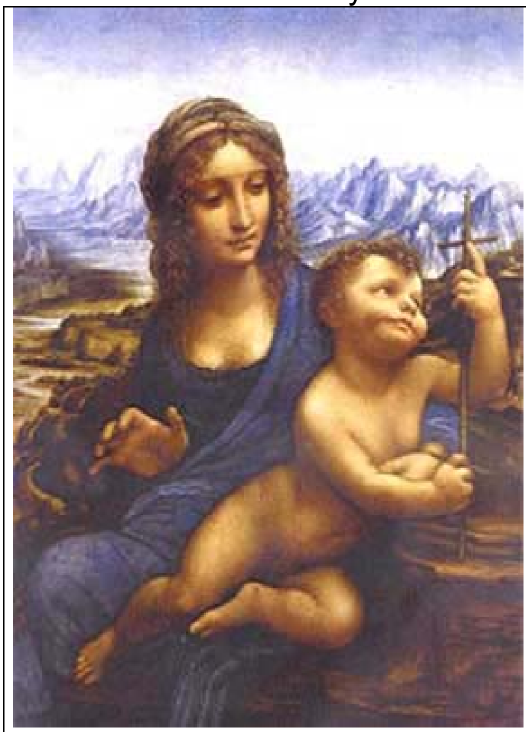


Version Louvre, Paris	Version Cheramy, CH	London, National Gallery

3.2.1 Propositio


Windsor Castle paper n. 12514

3.2.2 Ratio
La Madonna dei Fusi by Leonardo




Version Ex Redford

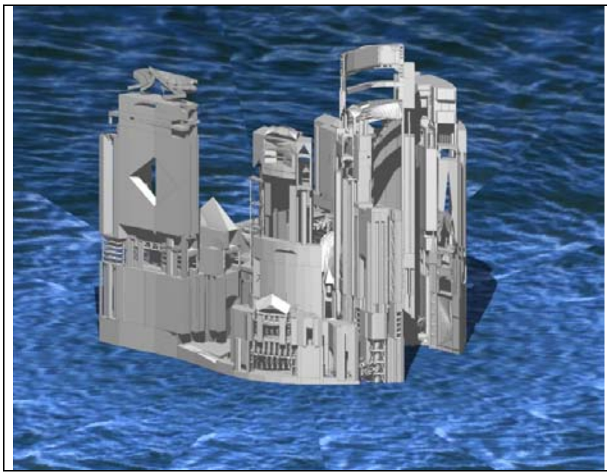
Version Buccleach

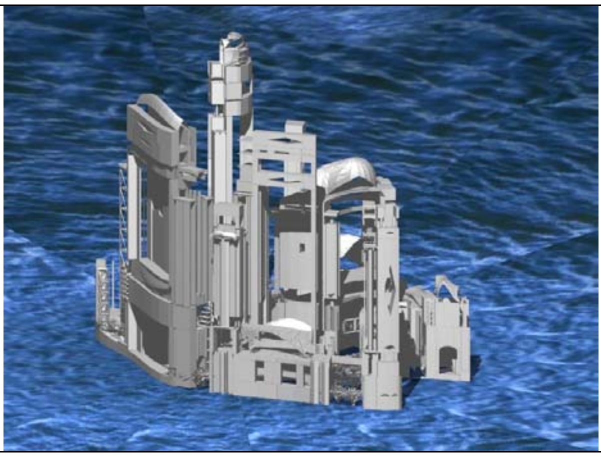
3.3.1 Propositio

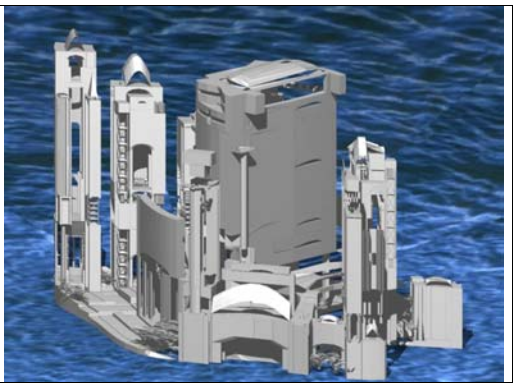
Reversed perspective, St. George Church at Madaba, Jordan

3.3.2 Ratio

3 Scenarios of the same Ideal city code, La città Ideale, by C. Soddu.







In pausa / Stand-by
Ora potrei portarmi / Now I could carry me
Nel mio piccolo lembo / In my small strip
Di terra silente / Of silent land
Mi trattiene l'emozione / Emotion keeps me
Di smarrirmi vedendo: / From losing my way seeing:
Il ricordo riafferma la meraviglia / Memory riaffirms my wonder

4.1 Confutatio
To touch to see, memory as flow to new hypotheses
"…the soul is analogous to the hand;
for as the hand is a tool of tools,
so the mind is the form of forms…"
Aristotele, De anima, 432a

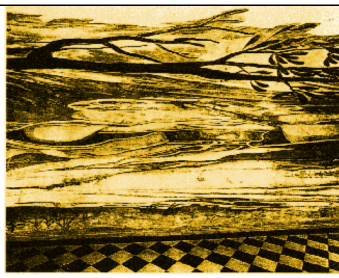
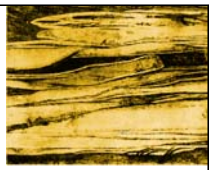

Similarity/Difference
Il silenzio è nel mio cuore/Silence is in my heart
Che cosa so che non vedo?/What do I know that I don’t see?
Mia cara, lo sai che sono qui/My darling, you know that here I am
Ascolto, al buio, il coro della notte/I listen, in the darkness, to night chorus
Che ha superato l’agonia/That overcame agony
Nella speranza del giorno già riflesso/In the hope of already reflected day
Apparenza inerte del sublime/Inert appearance of sublime
E’ luce sullo splendore/It is light on the brightness
Ancora una volta e per sempre./Once again and forever.

5.1 Confirmatio
Micro/Macro interchange:exciting expression







6.1 Conclusio

Figura is not only what appears, but also a tool for impressing in human mind a cognitive identity process.

Figura is a ***mirror*** in which each people can discover ***how*** his vision becomes reality, through emotion of seeing identical aura uniqueness.

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Modular Perspective as a Method for Generative Design

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Abstract

Apparently there are many methods for perspective but if we categorize them there are just a few. Some criterions of classification relate perspective to the so-called 1-point, 2-point and 3-point methods, others —more formally— to projective geometry, descriptive geometry or vectorial algebra. Of course we cannot forget to mention the early treatises on perspective such as Alberti's *Della Pittura* or Piero's *De Prospectiva Pingendi*, which escapes any classification. Our aim on this article is not precisely to solve the classification problem rather we propose a new comprehensive method for perspective, capable of 3D representation without using vanishing points.

The *modular perspective* method allows us to work in true three-dimensionality on the perspective plane (*PPl*). We will explain how to measure directly on the *PPl* the triad coordinates (*x, y, p*) of a given point into the visual space, and how to play with the symmetrical planes X and Y (*SPl X/Y*) in order to generate or recover data. Finally we will explain how to employ *modular perspective* in *generative design* formal-process through an example of application.

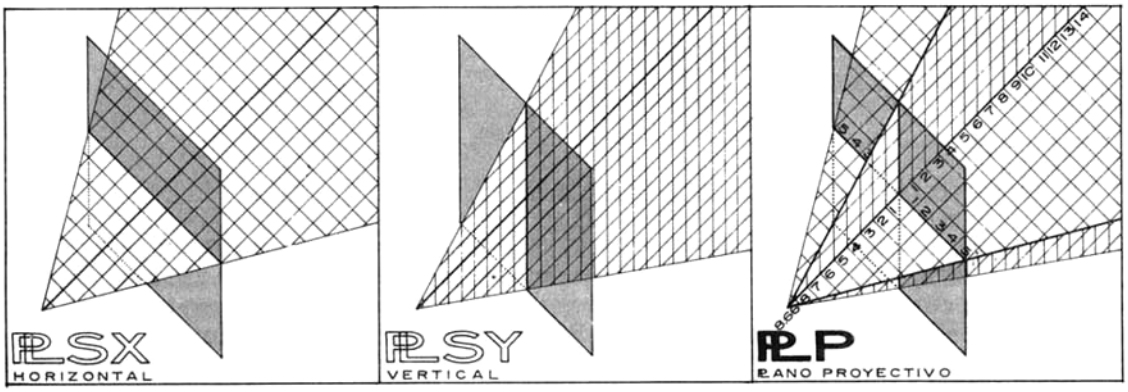
1. Spatial Perspective Versus Object's Perspective

Our first analysis is focused on the difference between the perspective of the observer's visual space and the perspective of the objects. Alberti's method for instance, describes the observer's visual space by means of a reticulated grid —as a measuring system; opposed to traditional methods that pursuit solving the perspective of the objects alone. These methods lead us to understand perspective through two different models: The Albertian, as a geometrical system of human vision and the traditional as a repertory of geometric recipes to solve figures in perspective.

But what does spatial perspective versus object's perspective mean? A scientific explanation can be given through the human vision itself, but our purpose here is not to study the neuropsychological processes of vision —a very complex process indeed—, rather we pursue to interpret human vision throughout geometrical concepts.

From Renaissance perspective we inherited the *visual pyramid* model —with its cutting plane or *window*. But this model has an important feature not very well understood even nowadays, and that is that only *one vanishing point* can be located in it. In other words we can ask: How many vanishing points does the *visual pyramid* has? A question that challenges us to explain how perspective can be conceptualized through the so-called vanishing points methods. As we know these methods are based in the cube's geometric properties instead of a model of the human vision [1].

The *modular perspective* model represents the observer's visual space in the same manner the Albertian *visual pyramid* does, in such a way that our sight line runs from the pyramid's vertex toward infinity. The symmetrical plane X (*SPl X*), the symmetrical plane Y (*SPl Y*) and the *PPl* are the basic components of the *modular perspective* model, as it is show in **Figure 1**.



What the observer perceives through the *PPl* is the object's apparent size because its length, width and height dimensions change as we move forwards or backwards. In any case the apparent size of what we perceive is ruled by visual triangles. This geometrical feature means that all visual triangles are proportional and thereby the *PPl* can be placed it at any depth in the model.

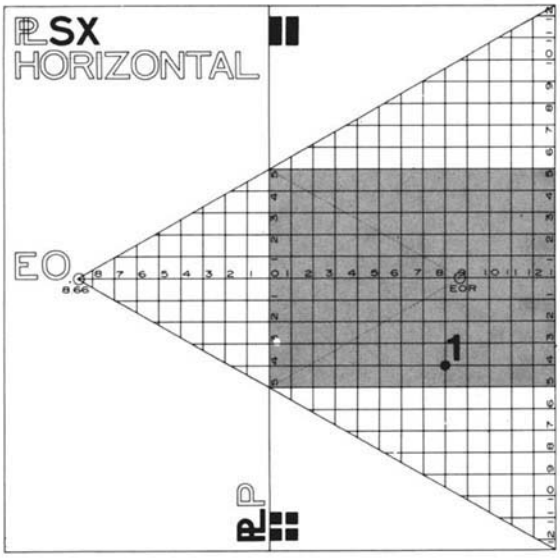
Notice that the *observer* (o) and the *SPl X/Y* vertex share the same origin —contrary to those vectorial models in which two origins are required—, so we can easily measure the width, height and depth (*x, y, p*) of any given point into the visual space. As the three planes of our model correlate to each other, the coordinates (*x, y, p*) can be read directly on the *PPl*. The remaining question here is: where the *vanishing point* (*pf*) should be placed? As the reader might suppose, the intersection of the *SPl X/Y* determines the *symmetrical sight line* (*vs*), where (o) and (*pf*) are located at its ending points. In other words, the point at the center of *PPl* represents the (*pf*). This geometrical feature allows sketching in perspective in a true three-dimensional plane, that is, on the *PPl*.

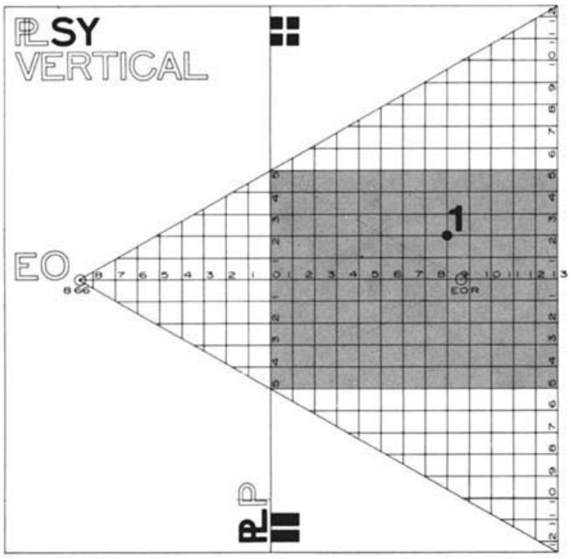
2. Measuring Points on the *PPl*

Our method consists on determine the (*x, y, p*) coordinates of a point (P*n*) in the space under the *modular perspective* geometric procedure —since the numeric one is more suitable for computer applications. There are five cases of punctual perspective projection into the *PPl*. We will present here in full description the first case, since the other four cases will be posted on the Internet soon [2]. Our description, rather practical than theoretical, starts with the problem statement and then after with its solution.

Case 1. Problem

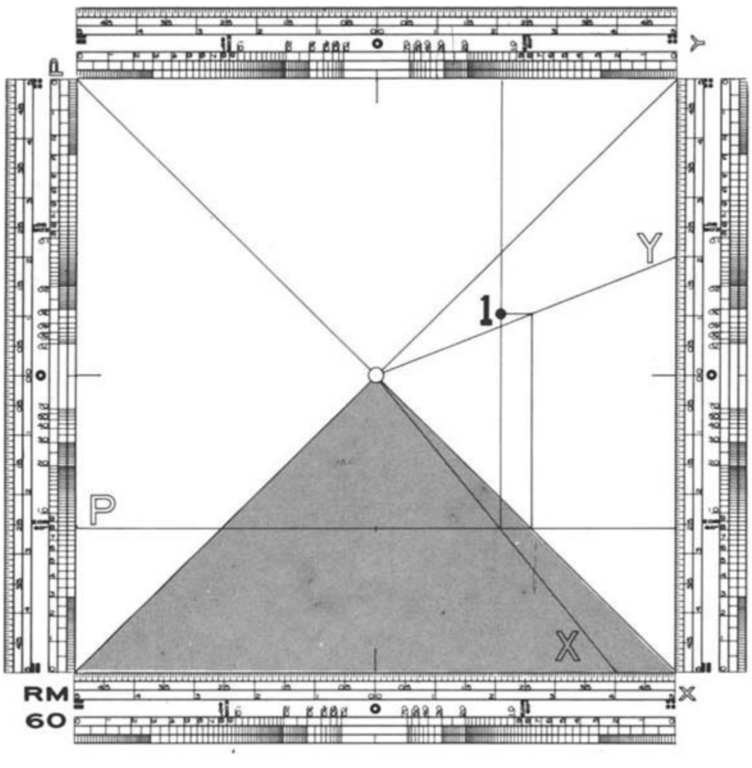
This case occurs when the values of (*x*) as well as those of (*y*) are not greater than ±5 *m*, and when (*p*) has a positive value. As can be seen through the *SPl X/Y*, in **Figures 2** and **3**, the coordinates of point P1 are plotted within the shaded area of both planes.





Case 1. Solution

This case is the easiest of all to solve. When (*x*) and (*y*) are less than or equal to ±5 *m*, they are drawn directly using the *Salgado Modular Scale* (RMS). We can see in **Figure 4** how to draw P1 in perspective:

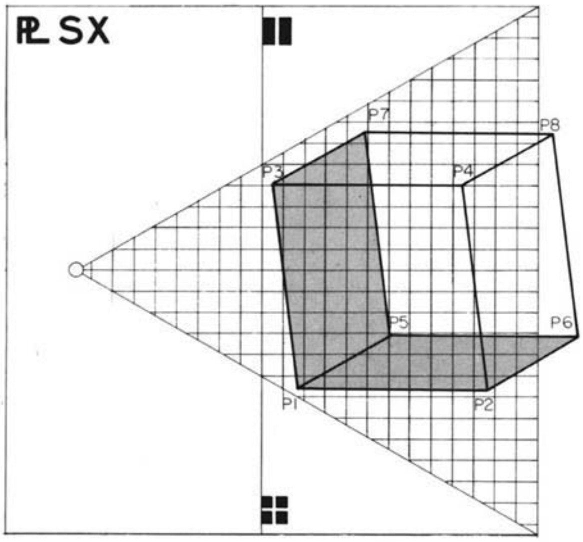


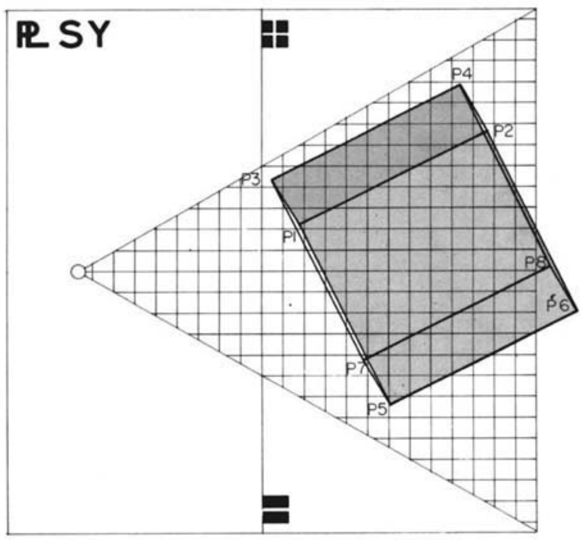
- *x* = 4.00 *m*, measure on lower border and take to (*pf*).
- *p* = 8.00 *m*, measure on the left border and draw it the width of the visual field, where it intersects (*x*) draw as ⊥ to (*p*). The problem now consists on finding (*y*) on this ⊥.
- *y* = 2.00 *m*, measure in right border and take to (*pf*). At the intersection of (*p*) with the diagonal raise another ⊥ to (*p*) until it meets (*y*), from there draw a horizontal line to the ⊥ (*x, p*), and this intersection determines P1 in perspective.

I am aware that this could sounds very much mechanical because we are not using simple words to tell what is going on the *PPl*, but this is the only way to avoid mistakes. Nevertheless, lets try another manner of understanding what we did to obtain P1:

- Imagining the *PPl*, as a sheet of glass in front of you and a *point* behind it, then try to follow by sight its three spatial coordinates into the real space while observing the *PPl*, and you will realize exactly what we did above to obtain P1 in perspective. Repeating this procedure for other *points* will confirm you that (*x*) and (*y*) always vanish to (*pf*) while (*p*) relates to them transversally in depth.

Lets see now the classical example of a cube in perspective this time without using any vanishing points aid but the (*pf*) alone, that is, taking the cube as a referred object into the visual field. **Figures 5** and **6** show us the cube's projection on the *SPl X/Y*, so the (*x, y, p*) coordinates of each of its point can be read onto them.



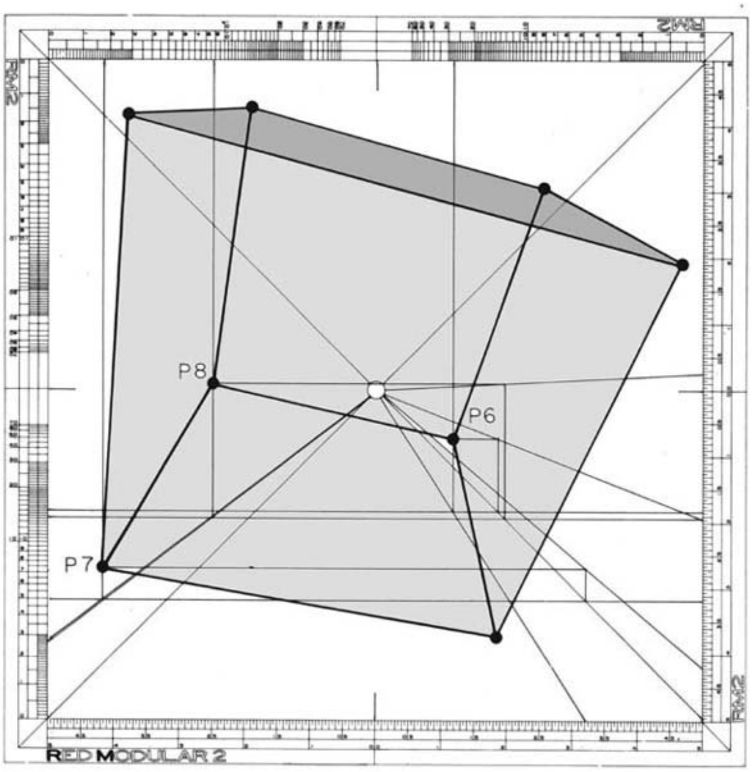


Do not worry about the geometrical accuracy in reading coordinates on these planes since our *visual-measuring* approximation is reliable enough to accomplish this task. For instance, when reading P3 coordinates we can have:

$x \approx -4.05$ or -4.10
$y \approx 4.40$ or 4.50
$p \approx 0.50$ or 0.60

When the *SPl X/Y* are larger than the illustrations posted here the coordinates read would perform the same way as if using the customary scale-meter, which in our case would be done through the RMS complementary scales.

Remember that we are employing *modular-scale* values all the time, which means that the cube can take any size depending on its pre-establish dimensional equivalence, so our example can either be as short as a cube-toy or as large as *La Grand Arche* building (Paris). You can image these two extreme examples on the cube's **Figure 7**.



The three scales on the RMS can be enlarged or shortened as we choose beforehand. If you want to render a perspective on a mural surface you can outline it right there on the wall, avoiding the inaccurate *quadratura* procedure or wondering where to pass through on the contiguous walls to locate the vanishing points you might need. The RMS more noticeable advantage is the freedom we get in controlling the drawing's size, as big or small we wanted to.

It is easy to render a perspective by using the *SPl X/Y* data. This technique is part of the students training in *modular perspective* in order to enhance their spatial abilities. They have to read the *SPl X/Y* data in order to interpret it on the *PPl*, that is, to learn how the 2D-3D transformation works. In the outmost level of training, students learn how to visualize objects in 3D only, by attempting to design architectural forms directly on the *PPl*, the same way they use to do in planar projections. Thinking in two-dimensions can be complicated some times but thinking in three-dimensions is a real challenge, due to the fact that our brain's right side must operate highly complex spatial relations.

3. *Modular Perspective* and Generative Design

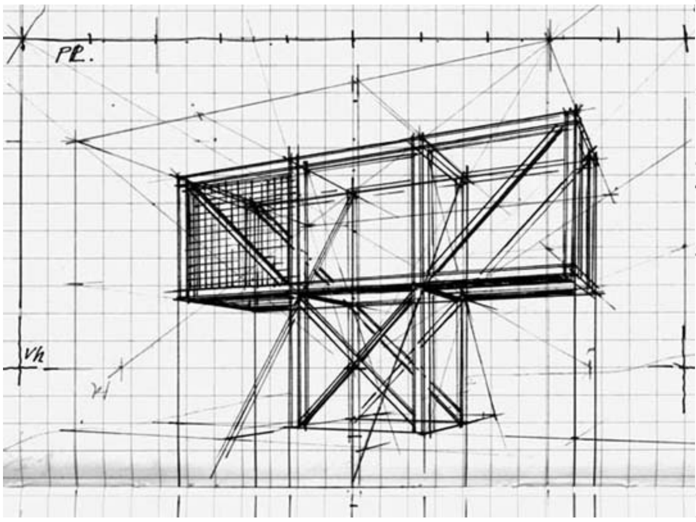
I do not know what could it be for other schools of architecture, but at mine —and for many years until nowadays— the perspective outlining of a project is the last thing to do. In other words, the customary design process is born in 2D sketches, matures either way, and gets old in 3D. So, our perspective's *vangelio* suggests for it to be born in 3D at once.

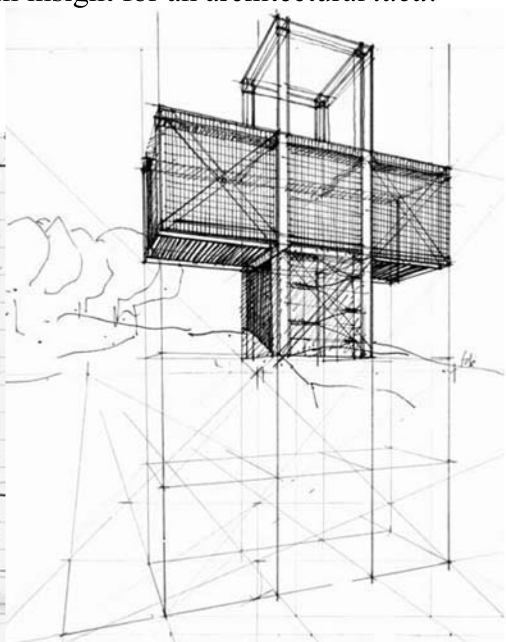
Celestino Soddu quotes in *From Forming to Transforming*: *"In every project there is a first step. The designer knows that his first act has a precise purpose: he has to trace a system of relationships that must be adaptable to each possible development."* [3] Certainly the *idea* must be grasped as the first act of design, but what matters more is the way we choose to approach it. As we know creativity involves the utmost complex brain operations not susceptible for translation into a method of any sort, so there can be many ways to approach the *idea*. The more we can say about it are generalities such as choosing between sketching in 2D or in 3D, a choice that depends upon our spatial abilities to perform the one or the other.

For sketching an *idea*, either in 2D or in 3D, computers are not yet suitable for problems solving into the vast field of creativity, that is to say, they seem not to enhance human creativity, and even more, as Van Doren says about *companion computers*: *"They will make life very pleasant, but they will no much change, and certainly not improve, human nature."* [4] They are just tremendous processing tools but incapable of really helping the act of creativity that involves personal perceptions and emotions. Artificial intelligence (AI) plays an important roll in computer systems, pursuing the way to emulate human behavior. Burton points out that: *"Both AI (particularly symbolic AI) and drawing theory came to model human behavior as information processing."* [5] Cleary the new lead to follow seems to be the so-called *drawing theory* that becomes a seriously research topic for neuropsychologists, meanwhile designers starts to be interested on the subject too.

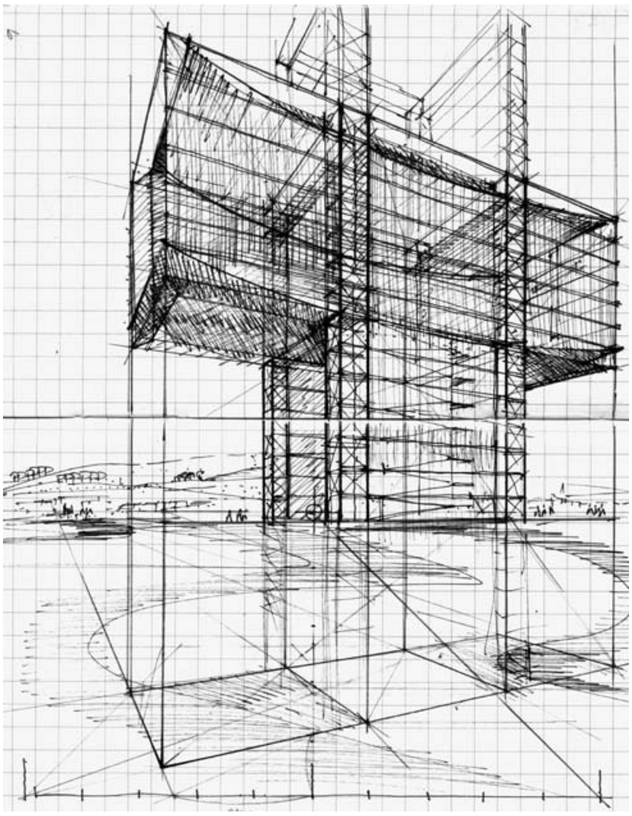
When a children is asked to draw that what he is looking at, he draws what he knows about that thing instead of what he actually is seeing, because he has not been training to interpret and play with spatial relations. But when an architect is asked to draw that which does not even exist is a big challenge, because he does not know from where to grasp an image? As we know he need to crate it. Before to conceiving any image designers start working very much like a child does, gathering first all the pieces that they already know about the theme and then after reassembled them in a new way, by adding or taking away elements, repeating this process several times until the *idea* is done.

For our 3D sketching example *idea* we choose to design a Christian Church, to be settled in the valley of México. It is worldwide known that the *cross* is the most powerful symbol for Christians. There are many churches around the world expressing the *cross* in many ways, mainly through its architectural plan layout or at the top of the towers and vaults as a sculptural ornament. Thinking about this symbol —during a sermon in Union Church (México)— my very first thought was: why not consider the whole building as a cross? Perhaps a church like this already exists somewhere. I am not claiming here its originality but its origin, as an insight for an architectural *idea*.

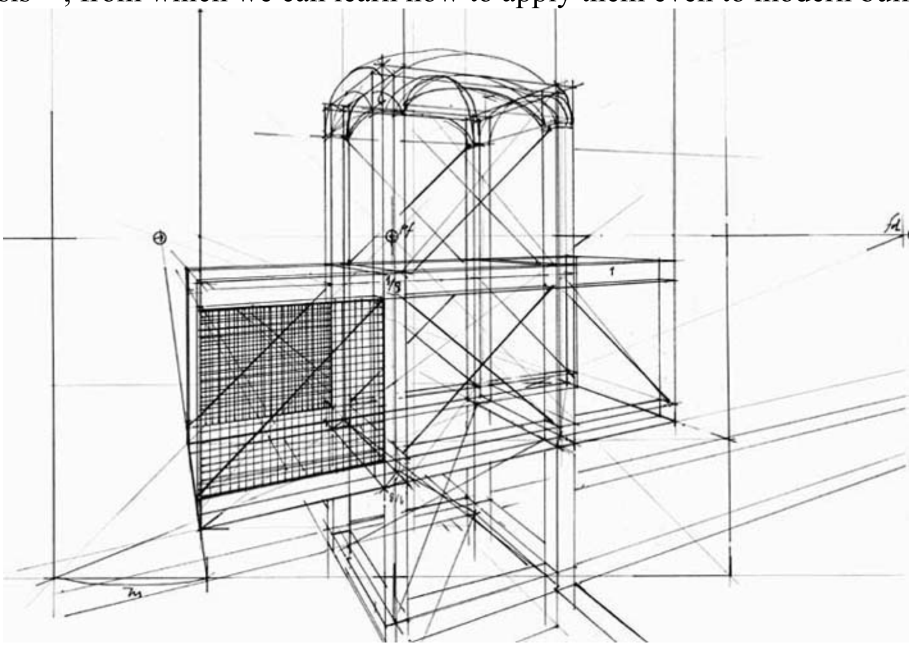


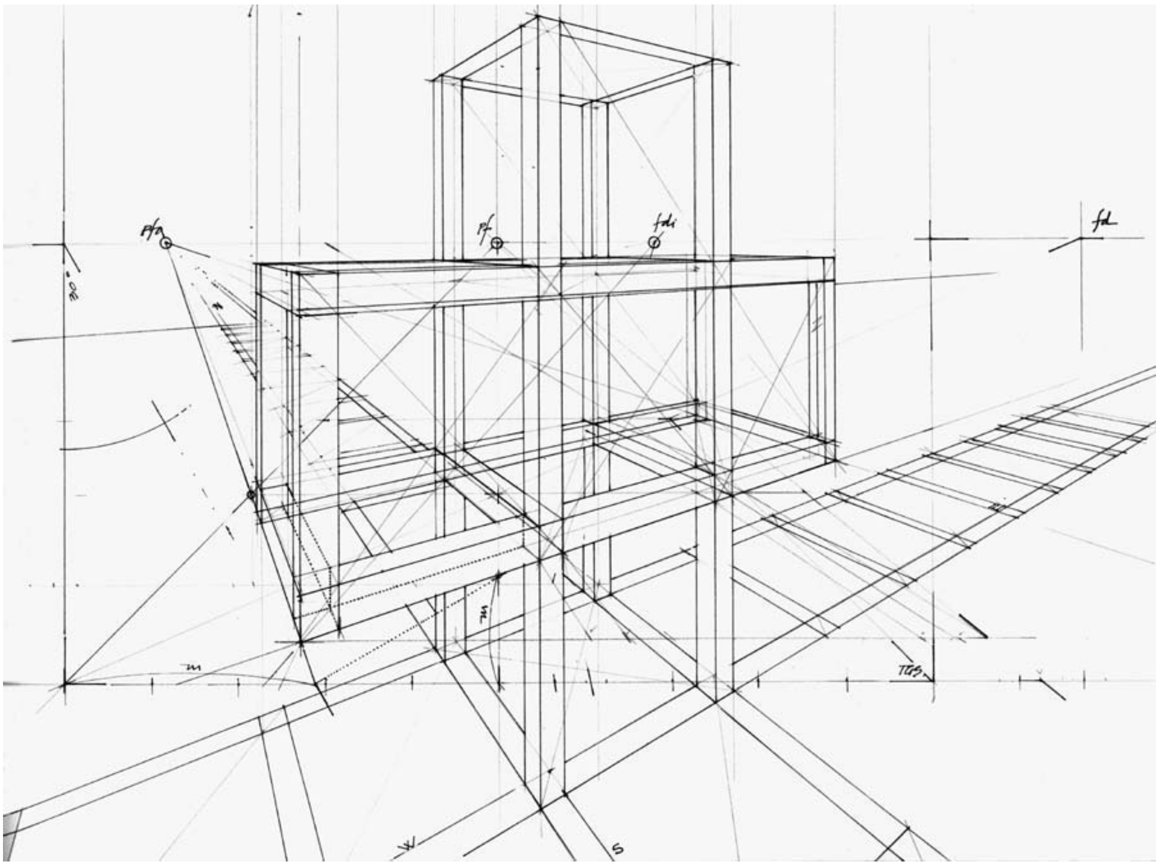


Our first attempt was to visualize the *idea* formally, as it is showed in **Figures 8** and **9**. During its execution some questions arouse immediately, such as: What dimensions are we dealing with? What structural system and materials must we think over? What colors would be suitable for the curtain glass windows? Under which criteria should we select the landscape settlement? And so on, many other questions come up. Our second attempt went into the volumetric configuration, discovering more problems to solve. See **Figure 10**.

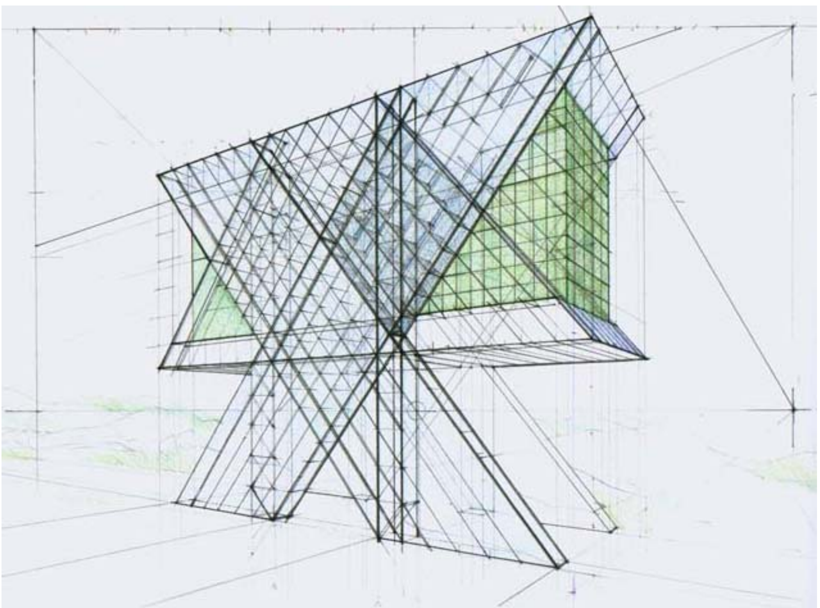


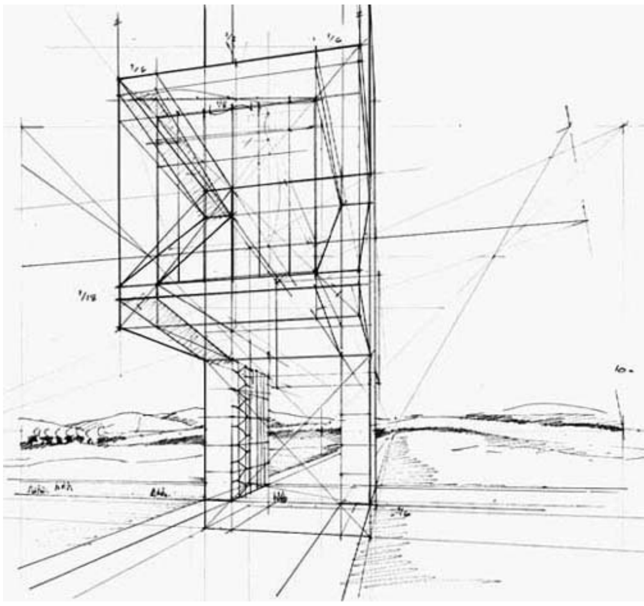
Having these questions in mind, we introduced in our third attempt the *architectural layout of proportions* in order to rule the composition, as we can see in **Figures 11** and **12**. Vignola and Palladio were the masters in architectural design through *proportions* —as well for historical building analysis—, from which we can learn how to apply them even to modern buildings.

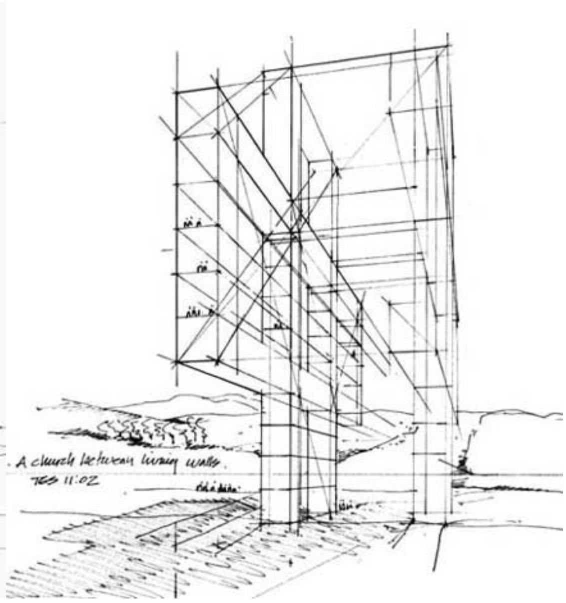




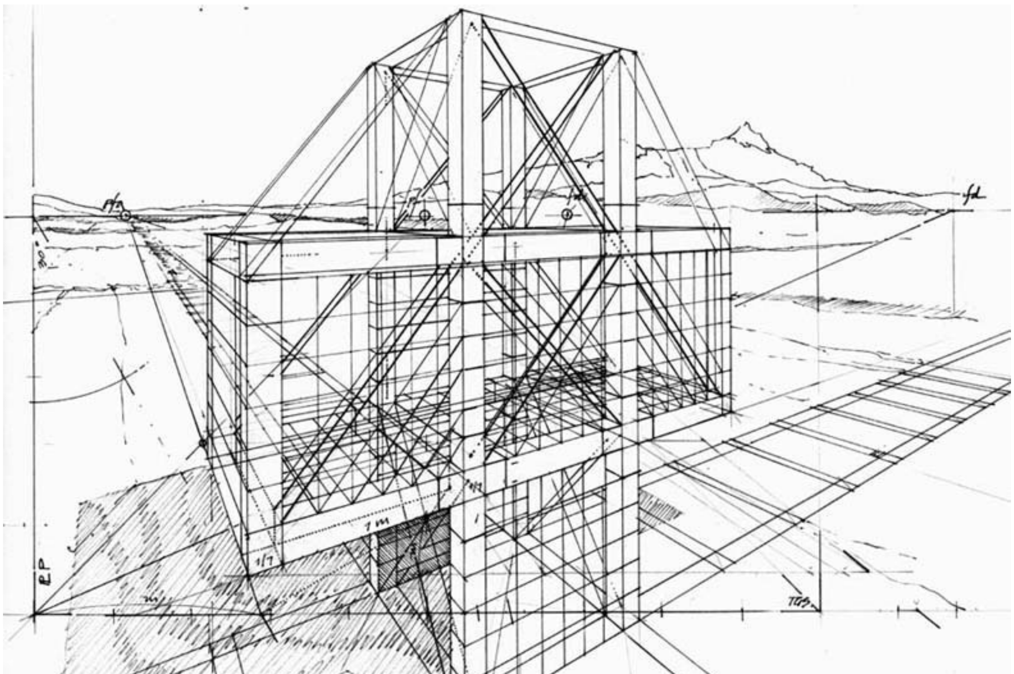
As a result of this 3D sketching process we grasp a *code* to explore, as Soddu says: “This first design act is the occasion to use the code as a means of possible transformations, and the traced form is a frozen moment of this transformation process. We are not able, in fact, to transform a white sheet: we trace a form transcribing our memory a spark of the idea.” [6] So we decided to explore the *x-cross* composition as another possible transformation of the original *code*, being careful to notice when its meaning changes radically, to step back immediately, as it occurred in **Figure 13**. We realize at this point that a *code* cannot be broken without changing the *idea*. A *code*, as a system of architectural elements, can be transformed over and over until it reaches one of its possible arrangements.







Working on the *code* our *visual thinking* starts playing its role in the process, as Arnheim says: “Our thoughts influence what we see, and vice versa.” [7] And that indeed happens. Until we turned the view’s perspective, as it can be appreciated in **Figures 14** and **15**, we realize that the large lateral walls forming the cross could be capable of holding all the complementary activities of the church, as small independent buildings linked by the sanctuary, in other words, *a church between living-walls*. Of course we tried to find out a meaning for the *living-walls* from the historical point of view. Observing a perspective section of San Peter (Rome, ca. 320-329), the four lateral aisles accomplish an important structural function as well as housing complementary activities. So we thought that the basilical spatial configuration —of two lateral aisles, in this case— could match pretty well for the *living-walls* without destroying its vertical expression, that of the cross.



Once the *idea-code* was reached a feedback process begins reformulating our original inquiries, but this time giving them architectural answers. That is the case of **Figure 16** in which we feedback

Figure 12, improving its architectural elements. After this final attempt we find ourselves ready to develop the architectural drawings; plans, elevations, sections and details mainly. The quality of this process depends upon our professional training and capacity as well as the teams we work with — for structural calculus, contractors and so on. At this point there is no more *idea* to grasp or a *code* to transform but the building process alone.

I would like to close this writing going back to the concept of *idea* in *generative design*. At least in architecture, an *idea* is always three-dimensional, or better said, fragmentary-three-dimensional. Soddu gives us a great example recreating the possible requests made to Borromini for Sant'Agnese: "I imagine the request made to Borromini for the church of Sant'Agnese in Piazza Navona: I want the church be present in the whole square, inside the square but, at the same time at the limit of it; the dome has to be present in all the square, it has to move itself amplifying the character of the square that is a lengthened elliptic Roman passage." [8] As we can notice all verbal-requests evoke 3D images otherwise it would be as tedious and useless to translate it into 2D "ideas."

When Renzo Piano decided to build in stone the new cathedral for Padre Pio, in San Giovanni Rotondo (Italy), he took the *arc* as its *code* through which a 360º view from the interior was generated in response to the infinite landscape. His *code* rested upon the *stone* and the technology to carve stones in different sizes using a computer program —because the arcs, all of them, have different spans too— as if they were standardized production. This is one of the many ways in which computers become a designer's friend. Borromini's *idea* was probably to connect in harmony its church with the surrounding space. Renzo's *idea* matches in his own words: *"Architecture is always the construction of emotions through technical means."* [9]. Our church's *idea* suggests that architectural forms can be conceived and transformed within its natural dimensions.

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[2] perspectivegeometry.com
[3] Celestino Soddu, "From Forming to Transforming" (paper at GA 2000 Conference, Milan 2000) generativeart.com
[4] Charles Van Doren, *A History of Knowledge* (USA: Ballantine Books, 1992) p. 381.
[5] Edward Burton, "Artificial Innocence: Interactions between the Study of Children's Drawing and Artificial Intelligence", Leonardo, Vol. 30 No. 4, pp. 301-309, 1997.
[6] Soddu [3]
[7] Rudolf Arnheim, *Visual Thinking* (USA: Univ. of California Press, 1969), p. 15.
[8] Soddu [3]
[9] Renzo Piano "Building and Emotion, Église du Padre Pio, San Giovanni Rotondo" Techniques & Architecture, Vol.—, No— (199-).

Architectural Interpretation of Cellular Automata

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Abstract

Mathematical constructions and concepts can be utilized in a number of methods to investigate the process of generating architectural forms. One is to technically layout architectural elements along such constructions, another is to explicitly develop forms corresponding exactly to the underlying concept, and another is to use such concepts as inspiration, a starting point for design. A hybrid method is to follow an interpretive approach, one that uses a mathematical concept as a framework to begin to investigate architecture forms. Architectural considerations are applied both at the beginning of the process and continually throughout the process as a better understanding of the underlying concept is developed. This paper attempts to use cellular automata is such a way. The process of investigating such concepts, it is believed, will help other such approaches, as well as, more traditional approaches of design development.

1. Introduction

Cellular automata is the computational method which can simulate the process of growth by describing a complex system by simple individuals following simple rules. This concept of simulating growth was introduced by John von Neumann [1] and further developed by Ulam [2] in the area of simulating multi-state machines. The concept gained greater popularity when Martin Gardner [3] described John Conway's "Life", a game that generated two-dimensional patterns. Stephen Wolfram [4] began researching the concept to represent physical phenomena and has recently reintroduced the discussion in "A New Kind of Science" [5].

The connection to architecture is the ability of cellular automata to generate patterns, from organized patterns we might be able to suggest architectural forms. Cellular automata, viewed as a mathematical approach, differs from a traditional deterministic methods in that current results are the basis for the next set of results. This recursive replacement method continues until some state is achieved. Fractals and strange attractors are also created in a similar manner. Many digital methods in architecture are parametrically driven, Krawczyk [6,7], an initial set of parameters is used to generate one result. If an alternative is desired, the parameters need to be modified and the generation is repeated anew. The difference between these two methods is that in parametric methods the results can be easily anticipated, while in recursive methods the outcome usually can not. This offers an interesting and rich platform from which to develop possible architectural patterns.

The universe for cellular automata has evolved over a number of dimensions, Wolfram, one-dimensional, Conway, two-dimensional, and Ulam, three-dimensional. The three-dimensional universe is the one that we are most interested in.

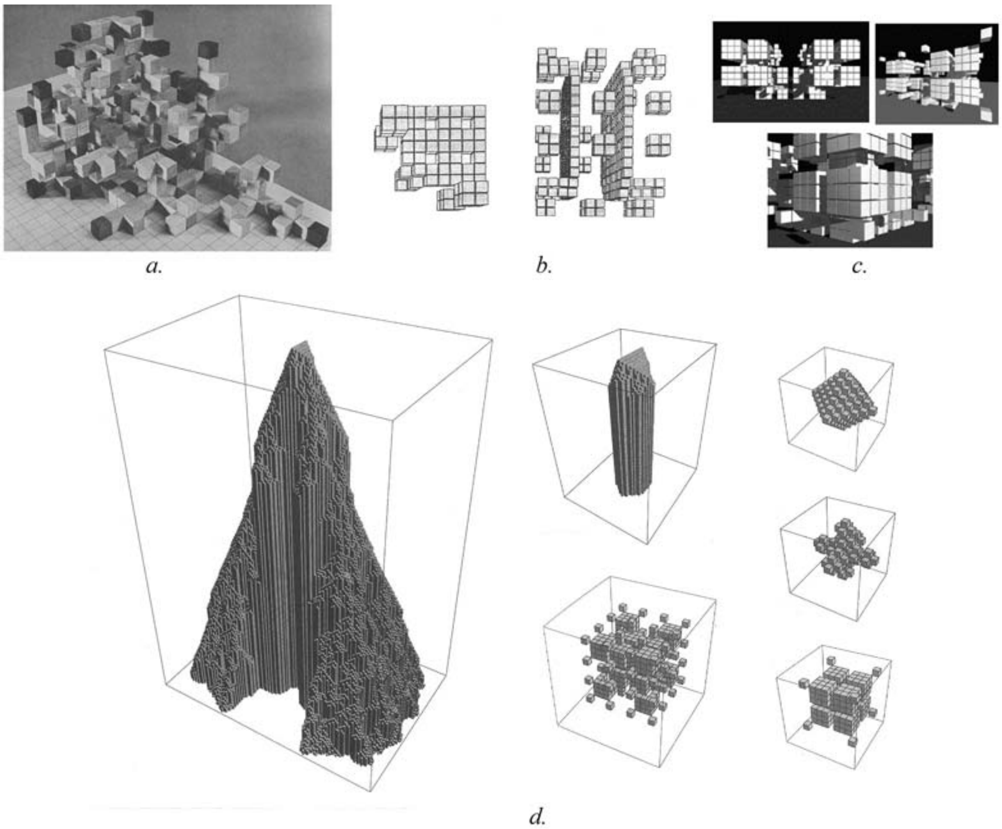

Figure 1. Three-dimensional cellular automata

An early example of three-dimensional pattern development is the wooden block model created by Schrandt and Ulam [2], Figure 1a. Investigating repeating patterns as Conway had found in two-dimensions is Bays [8], Figure 1b. and finally an highly inspirational architectural application by Coates [9], Figure 1c., much in the same spirit as Bays. The most recent is two methods develops by Wolfram [5], Figure 1d., in which a stacking method is explored, as well as, one similar to Bays. The striking similarity in these is the explicit representation of the cellular automata, even though each had taken a different approach and had a different application as an investigative goal.

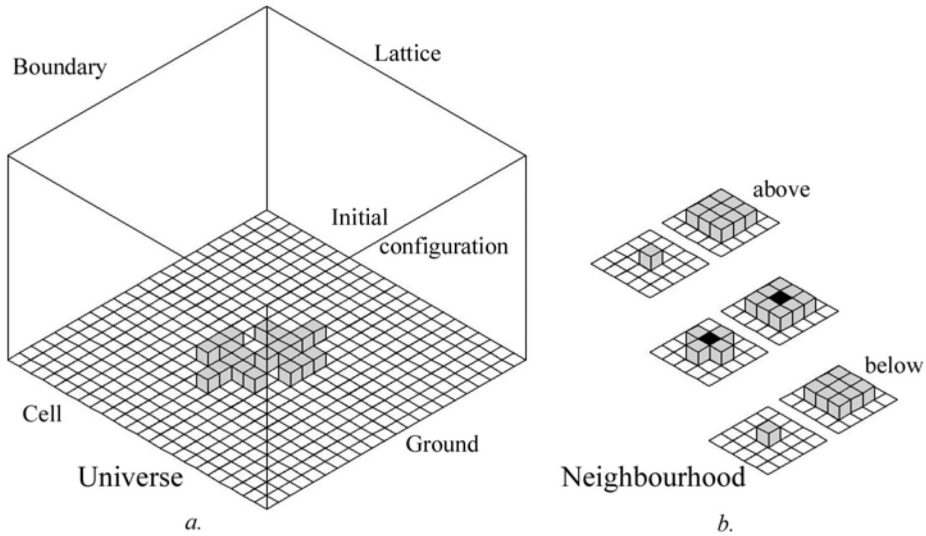

Figure 2. Basic cellular automata terminology

2. The basics

The three-dimensional universe, Figure 2a., of cellular automata consists of a unlimited lattice of cells. Each cell has a specific state, occupied or empty, represented by a marker recording its location. The transitional process begins with an initial state of occupied cells and progresses by a set of rules to each succeeding generation. The rules determine who survives, dies, or is born in the next generation. The rules use a cell's neighbourhood to determine its future. The neighbourhood can be specified in a number of ways, Figure 2b. displays two common methods of determining which adjacent cells to consider. The rule developed by Conway is: check each occupied cells' neighbourhood, survival occurs if there are two or three neighbours, death occurs if there are any other number of neighbours, and birth occurs in an empty cell if it is adjacent to only three neighbours. As each generation evolves, one of four cases can occur over some period of time. Either the cells find a stable form and appear not to change; or they become what is called a "blinker" and alternate between two stable states; or all or a cluster of the cells become a "glider", a group of cells that begins to transverse the universe forever, or all the cells die, extinction. A variety of rules have been proposed, with Conway's being the traditional starting point.

3. Architectural interpretation

The pure mathematical translation of a cellular automata into architectural form includes a number issues that do not consider built reality. For example, Figure 3 displays an initial configuration, 3a., and its raw results at the 8th generation, 3b. The interpretation or translation to a possible built form can be dealt with after the form has evolved or it can be considered from the very beginning. Deciding to follow a combination of both approaches, as shown in Figure 2, a boundary is placed on the lattice to represent a site, along with a ground plane, and an orientation of growth that is vertical and to the sides, but not below. The cells are stacked over each other to create a vertical connection without a vertical displacement between layers of cells.

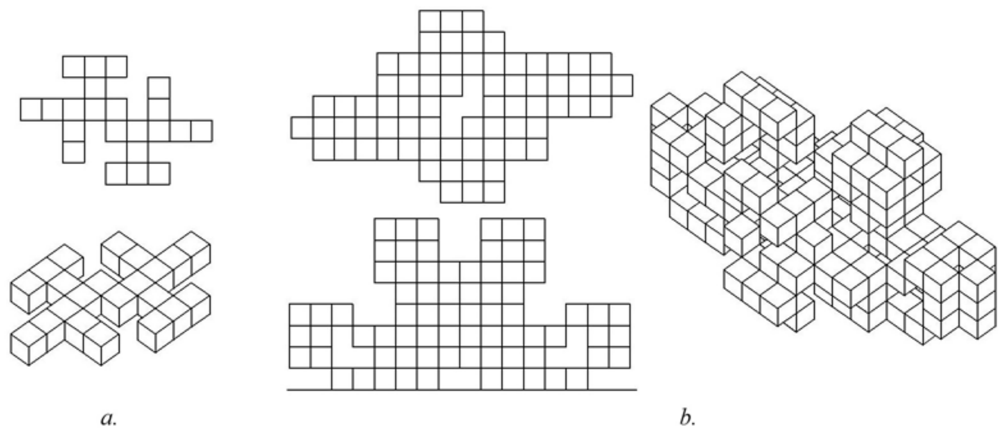

Figure 3. Sample generation

An initial review of the results highlighted a number of other issues; some cells were not connected horizontally to others and some cells had no vertical support. Also the cells do not have an architectural scale or suggest any interior space. Figure 4 displays a typical layer of cells and a series of interpretations that were made to address these issues, all of which are of interest architecturally. The centroid of each cell becomes the basis for this further development. The first issue is one of horizontal connections. Figure 4a. displays the initial cell configuration at a typical layer, each cell is adjacent to another. Cells are first joined together to form the largest contiguous floor areas possible. In this configuration, the cells that are diagonally adjacent do not connect horizontally. In 4b. the cell remains a square unit but is scaled so to overlap its neighbours. When joined, a small connector at the diagonals appears. In 4c. and 4d. , the scale of the square unit is increased to further develop a connector. The entire character of the exterior edge of the initial cells changes by these interpretations, as well as, addressing the interior horizontal connections between unit spaces. Additionally, a series of interesting interior openings begin to emerge.

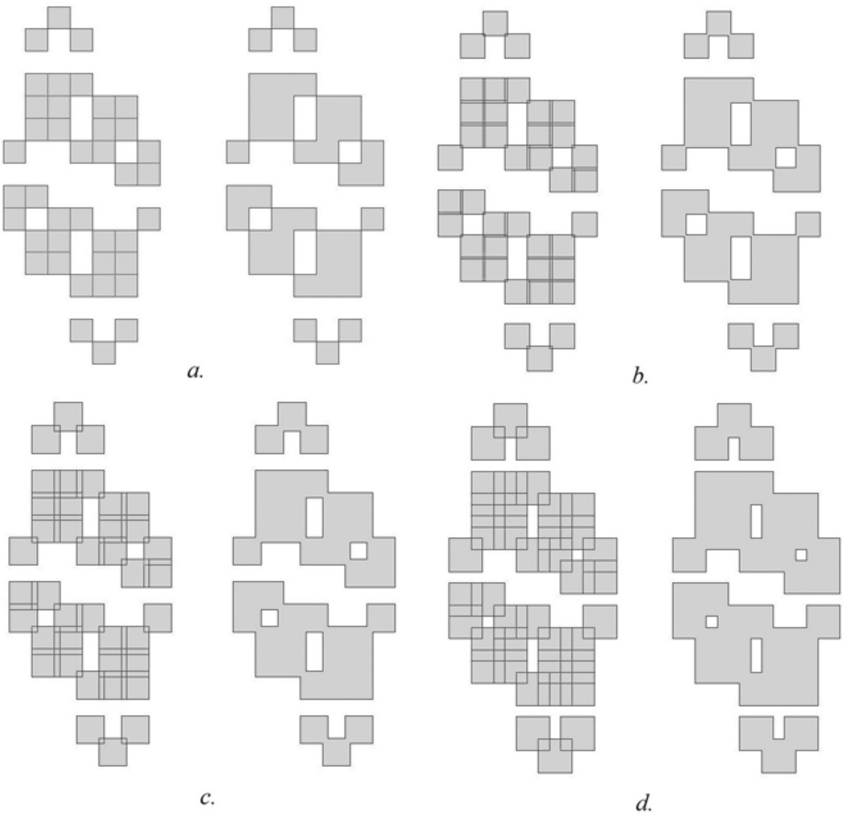

Figure 4. Horizontal connection of cells

In addition to a square unit, a variety of other shapes could be investigated that would articulate the building edge in other ways than the square and that could accommodate orientation and additional surface area in elevations for fenestration. Figure 5. displays a series of possible unit shapes: circular, super ellipse, rotated square, and a hexagon.

The joining of the units spaces, in addition to creating large contiguous areas, also creates a series of edge points, an envelope, that can be further given an interpretation or transformed. This envelope can be interpreted as a series of curve segments or a spline, as in the Figure 6. Depending on the type of unit shape, a variety of curved edges begin to develop.

As noted before, the initial cell configuration also lacked in having vertical supports. This issue could be addressed in the growth rules by limiting growth that had cell supporting it from below or to add supports to the final configuration. Figure 7. displays two possible support strategies, one with columns at the each cell corner and the second, columns located at the center of each cell.

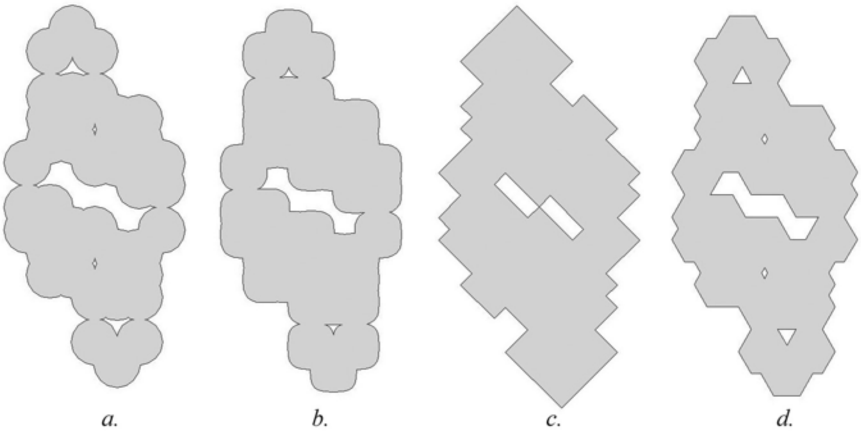

Figure 5. Variation of unit shape

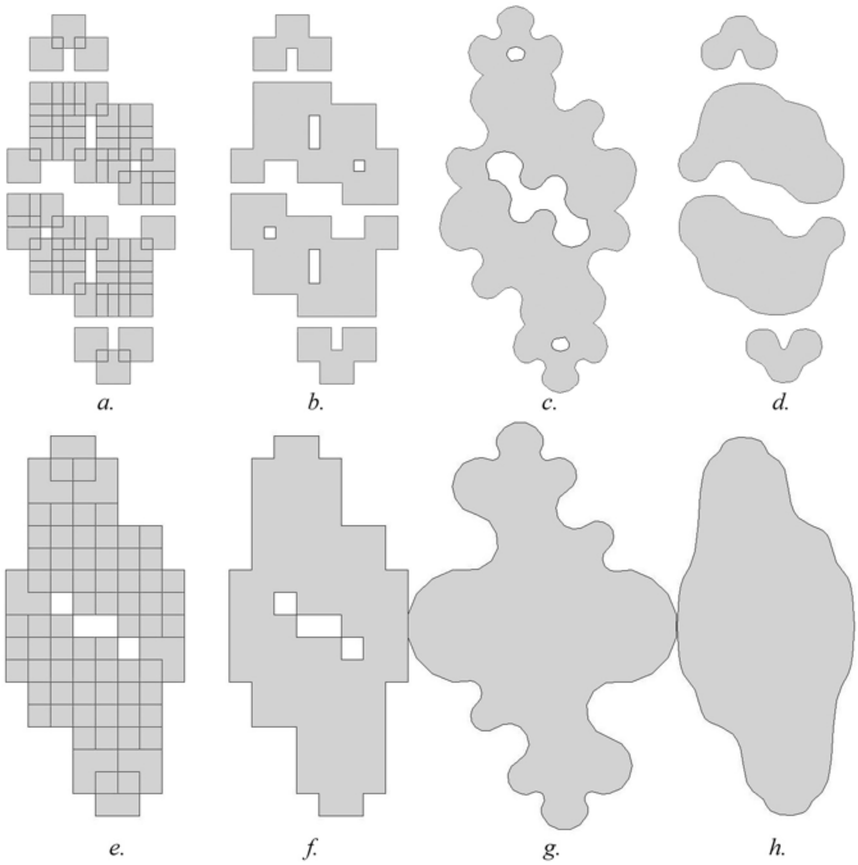

Figure 6. Envelope interpretation

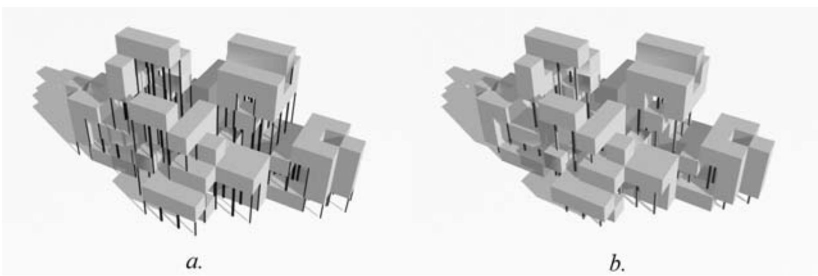

Figure 7. Cell supports

When seen in totally as in Figure 8. the following issues are also addressed. Displayed in 8a. is the raw cell configuration with supports represented as a mass model and with the cells represented as spatial modules of three floors each. Individual floor plates are included and each set of merged cells has a glass enclosure. In 8b. and 8c. are the curve and spline versions. One of the interesting aspects on this particular interpretation is the interior spaces created by the merging of the cells. A number of other merge schemes were investigated to further develop this concept. To articulate the edges of each layer of cells, a variety of spatial units, as shown previously, were also investigated.

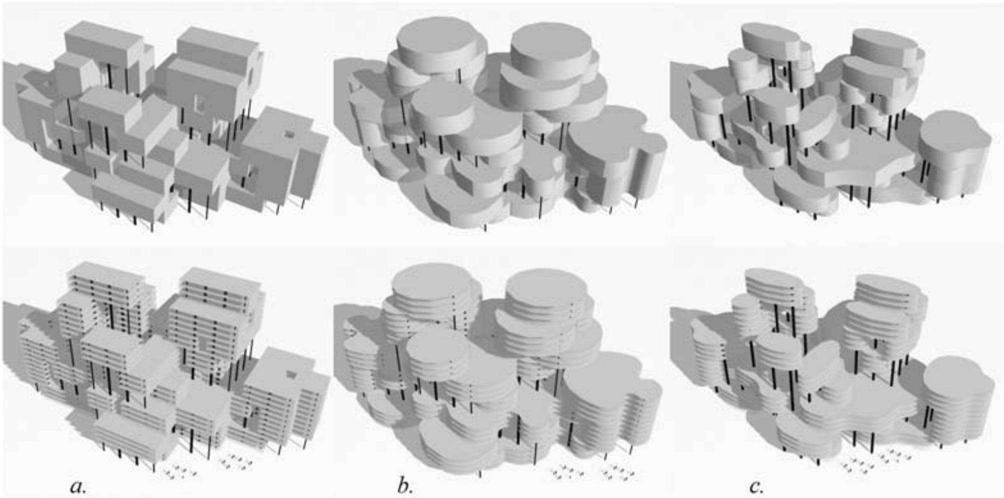

Figure 8. Basic architectural form series

Other approaches to the interpretation of the unit cells were also investigated. Figure 9. highlights an approach where the size of the unit cell is given a minimum and maximum, the actual size is selected randomly. The random method was also implemented in Figure 10., a minimum and maximum offset was defined for each vertex of a cell, then selected randomly. The shape in both of these cases remain approximately the same to the original.

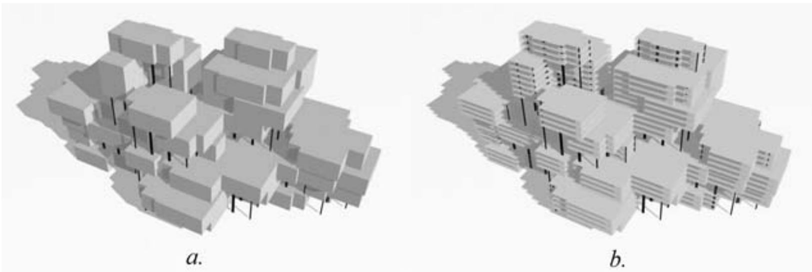

Figure 9. Cells of random size

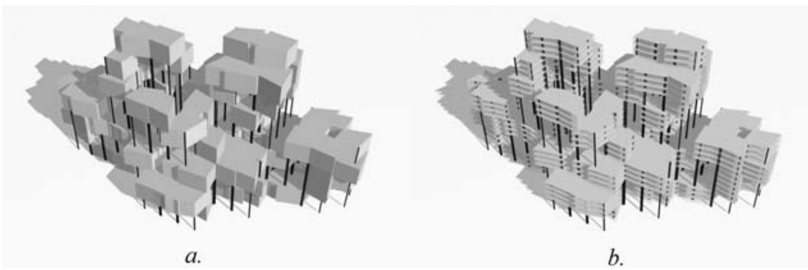

Figure 10. Cells with random offset of vertices

An entirely different approach was also investigated in that the vertical aspect of the stacked cells was considered as primary after the basic horizontal connections were made. Figure 11. displays one such example using the square cell unit.

The final concept considered was to interpret the cell formations as they are created. In this case, called retained growth, in each generation when a cell survives, it increases in size. This approach considers the actual growth process in the cellular automata and interprets it directly. Figure 12. display such a example.

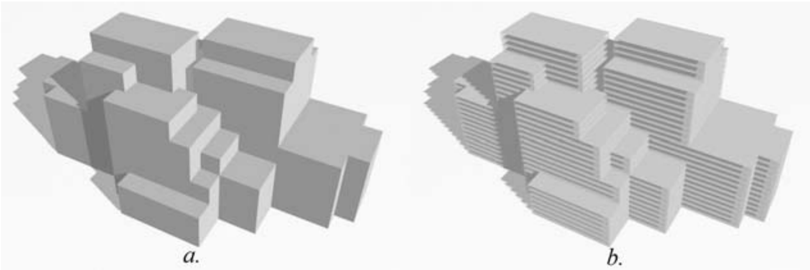

Figure 11. Cells as vertical volumes

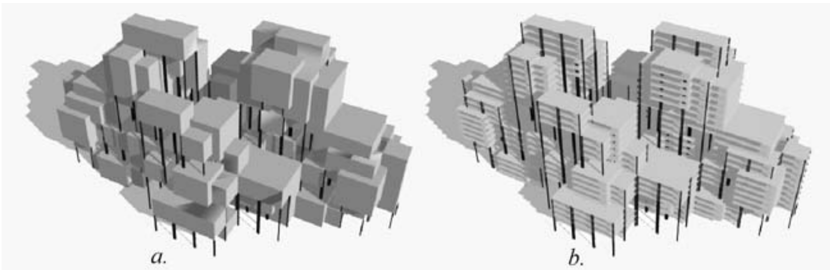

Figure 12. Cells with retained growth

Still other methods which have been developed by others, offer possibilities for future investigations. One in particular was suggested by Coates [9], Figure 13., in which the entire three-dimensional cell configuration is skinned with an envelope. The challenge would be to use this method but still embed the floor and unit space concept that was developed in this paper. The variety of methods on interpretation are only limited by the actual mathematics of the generating concept, the ability of the tools we use to model it, and our imagination.

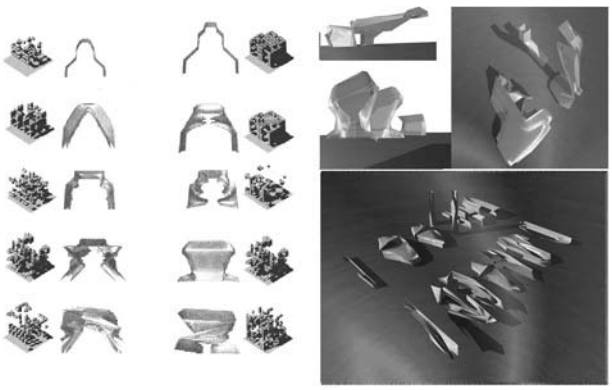

Figure 13. Skinned Envelope

4. Observations

The goal for this investigation has been to recognize elements of a mathematical concept that can be transformed or interpreted into architectural elements. Still many issues remain: what should be the initial configuration of cells, maybe Jean L. Durand's [10] compendium of neo-classical design rules, which generation to stop at, neighbourhood definition, type of growth rule, definition of cell, shape of spatial unit, overall scale, support conditions, lattice configuration, restriction to number or area of placed cells, introduction of existing or fixed elements, other concepts for connecting cells, and other methods to interpret cell locations. All of these issues, and others, can be addressed at the beginning of such a generative process and be developed or revised as the investigation unfolds. No one software tool can anticipate all the possible directions that can appear, each individual software module developed in this research is an specific response to something that has occurred. This enables the process to develop the unexpected, as well as, the architecturally possible.

The most important aspect of this research is the process; taking raw data from a generative method, finding a pattern and then defining methods in the interpretation of that pattern. The study and development of all the considerations that are encountered is the basis for better understanding the design process itself. The end results are not the goal, the goal is what can be learned in the process of generating them.

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GenJam in Transition: from Genetic Jammer to Generative Jammer

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Abstract

GenJam, short for Genetic Jammer, is an evolutionary computation (EC) based software agent that models a jazz improviser. Recently GenJam has evolved away from its roots as an interactive genetic algorithm toward its current state as an autonomous generative system. GenJam has retained its chromosome-based representations and mappings, its intelligent selection, crossover and mutation operators, and its real-time interactive performance capabilities. However, it no longer needs any explicit representation of fitness, which arguably makes it no longer an EC system.

This paper considers GenJam as a generative art system. Generative art produces "unique and non-repeatable events" that express a designer's generating idea. The designer's generating idea defines a *species* of events, represented in a genetic code. In music, these events could be individual notes, melodic phrases, even entire pieces. In GenJam the events are four-measure phrases, or "licks" in the jazz vernacular.

The format for the genetic code, then, defines a *species space* from which unique individual events can be generated. Uniqueness is important in jazz because improvisation must be spontaneous and "new." Hence, improvisation is tailor-made for the generative art paradigm, and in fact, one could argue that improvisation is, by definition, the purest example of generative art applied to music. In other words, generative music ***is*** improvisation, and GenJam is the Generative Jammer.

1. Jazz Improvisation and GenJam

Jazz improvisation is a highly spontaneous, highly interactive, highly creative activity. Jazz improvisers compose and perform simultaneously, usually accompanied by a rhythm section that typically consists of at least a bass instrument (upright or electric bass), a chording instrument (piano or guitar), and a drum set. In straight up jazz (also called mainstream, straight ahead, and several other labels) the group will usually begin a specific tune by playing a (sometimes) recognizable melody line, then improvise one or more choruses over the form of the tune, and finally play a recapitulation of the written melody to end the tune. The improvisational choruses are usually the focus of a jazz piece, and performers are judged by their ability to improvise compellingly.

Improvisers can perform in at least three modes: full-chorus solos, chase choruses, and collective improvisation. When taking a full-chorus solo, a performer improvises alone over the entire form of the tune, accompanied by the rhythm section. The emphasis is on presenting creative ideas and developing those ideas coherently to present an original melodic invention.

In a chase chorus two or more performers take turns improvising over successive portions of the tune, usually in units of four measures (trading fours) or eight measures (trading eights). The focus here is often competitive, topping what the other performer just played to show him or her up. This requires clearly hearing what the other performer plays and spontaneously finding a way to "play rings around it."

Collective improvisation is when two or more performers improvise simultaneously. The emphasis here is often on generating spontaneous counterpoint or harmony, complementing what the other performer is doing as he or she is doing it. This also can be competitive, but the goal is usually to weave a collaborative tapestry over the form of the tune.

GenJam is an evolutionary computation (EC) based, real-time interactive computer music system that improvises in all three of these modes in collaboration with a human performer. GenJam uses a chromosome-based representation for measures and phrases of melodic content and evolves populations of these individuals from which it generates improvisations in real time. GenJam's architecture, chromosome representations, mappings, musically meaningful genetic operators, and musical performance characteristics have been described elsewhere [1, 2]. This paper will focus on GenJam as a generative art system that applies the generative design paradigm to jazz improvisation.

2. Applying Generative Art to Improvisation: Lamps vs. Licks

The generative design paradigm focuses on the realization of "metaprojects…software that is able to generate an endless sequence of products" [3]. The designer's generating idea defines a species of products, represented by a genetic code. Unique individual products are generated from this species space in collaboration with the designer. In most generative design applications the products are usually complete, stand-alone objects, like lamps, for example [3], and the process, then, would generate a sequence of unique lamps, rather than copies of a single mass-produced lamp model. GenJam's "products" are phrases of melodic content, or *licks* in the jazz vernacular. An "endless sequence" of unique and original licks is certainly appropriate for improvisation, but there are differences between adapting the generative design paradigm to lamps and adapting it to jazz improvisation.

One major difference is that the licks played by GenJam are performed once and are then gone. The analogy to lamps would be to generate a new lamp every time someone turned on a light switch and then dispose of the lamp when the light switch is turned off. Improvisations are spontaneous products of the moment; once performed, they "dissipate into the ether" unless someone bothers to record them. This is an issue in jazz aesthetics, where major artists are often faithfully recorded at every performance because every performance is unique, will never be repeated, and (some would say) must be recorded for posterity. The problem is: who has time to listen to all the recordings? The philosophy with GenJam, on the other hand, is that improvisations are disposable; GenJam can always generate a new one if desired.

A second difference between generating lamps and generating licks is that the individual licks generated by the process are not stand-alone objects. A single lick must exist in two contexts to be meaningful: a harmonic context and a melodic context. The harmonic context is the chords being played by the rhythm section over which the lick will be played. GenJam handles this context by knowing what chords the rhythm section is playing at any given time and mapping the melodic content of measure chromosomes to specific pitches taken from scales suggested by those chords. GenJam understands 18 different chord types and also uses chromatic passing tones and other heuristics to generate melodic interest without sounding "wrong." The harmonic context in which licks are generated, then, is fairly straightforward. The melodic context, however, is more involved and is different for the three improvisational modes.

The melodic context of a given lick is essentially the licks that precede and follow it, the lick's place in an improvised chorus. When GenJam improvises a full-chorus solo, the surrounding licks are other individuals from the population. The constraints placed on a lick in this mode are minimal; GenJam literally selects licks to play at random. The path through the species space of licks, then, is fairly discontinuous, although since two-thirds of the licks are intelligent crossovers of the remaining one third, a melodic motive can be developed, albeit serendipitously.

When GenJam trades fours with a human in a chase chorus, its licks are surrounded by licks performed by the human. GenJam listens to the human perform a lick using a pitch-to-MIDI converter, maps what it hears to its chromosome structure, mutates the chromosomes to develop the lick, and plays the mutated lick as its response in the next four. In other words, GenJam uses its musically meaningful mutation operators to develop what the human has played into what it will play in response. The constraints placed on a GenJam lick in this mode are more pronounced. The "seed" chromosomes come from the human performer, and the modifications derive from the musically meaningful mutations, which include inversion, retrograde, transposition, and other intelligent operators. The path through the species space of licks for this mode is more continuous than for full-chorus solos because both the human and GenJam tend to play off of what the other just played.

When GenJam and the human performer improvise collectively, GenJam listens to the human while it is improvising. In essence, it plays an adaptation of what the human plays, delayed by a measure or a portion of a measure. Collective improvisation is probably the most challenging mode for humans to perform because the human must be thinking in three places at once: remembering what he played one measure ago, playing in the present, and planning what to play as a complement one measure from now. GenJam plays it safe in collective improvisation mode and only maps the pitches to the current chords without mutation. The melodic context in collective improvisation, then, is both the last measure and the next (future) measure. The path through the species space of licks in this mode tends to be even more continuous than when trading fours because GenJam is literally trying to parrot what the human just played, and the human is trying to complement that coherently. Clearly, this is a stylistic decision on the human's part. One can use this mode to play very intense avant garde improvisations, but I tend to play more inside.

A third difference between generating lamps and generating licks is that lamps typically are generated before they are used, while licks are generated as they are used, at least when GenJam trades fours and improvises collectively. This is important because there is no chance to reject undesirable licks in these improvisational modes the way one could reject undesirable lamps. Consequently, GenJam uses no fitness when trading fours and relies on its intelligent crossover and mutation operators to always generate appealing variations. If the human plays well, GenJam will too. Even if the human plays poorly, GenJam will at least sound competent. This need for spontaneous interactivity leads naturally to the ways in which GenJam collaborates with its human partner, which in turn provides some insight into collaboration in general between generative art systems and designers.

3. Collaboration: Designer Roles

The generative design paradigm is powerful because it can provide a stimulating and even inspiring environment in which a designer can explore a design space. The key factor in facilitating that exploration is the level of collaboration between the designer and the system. Designers need inspiration, and while that can come from within, it often comes from collaboration with others. Generative design systems can stimulate, provoke and challenge designers as they explore a design space through discovery, serendipity, and spontaneity. GenJam is a highly collaborative system that definitely provokes and challenges its human partner in performance. This section explores several forms of collaboration, using GenJam as an example.

One form of collaboration places the designer in the role of mentor [1]. When the original, interactive version of GenJam is used to train a soloist, GenJam improvises full-chorus solos while a human listens and provides simple real-time feedback on whether the improvisation sounds good or bad. The feedback is used to derive fitness values for individual measure and phrase individuals in their respective populations, which in turn provides the means to perform tournament selection and replacement while breeding new generations of the soloist. This is a traditional interactive genetic algorithm (IGA), where fitness is provided by a human because no algorithm can be devised to compute fitness values. In this type of collaboration, then, the system generates individuals, which the designer selects, eliminates or rates.

A related form of collaboration allows the designer to modify the system's generated individuals, instead of just selecting or rating them. This is a deeper level of collaboration because the designer is directly determining or at least directly influencing the content of the individuals. The disadvantage of this form is that the designer may over-specify the modifications and lose spontaneity, or in EC terms, the designer may converge the search prematurely. With GenJam the human performer collaborates in this way when responding to a four GenJam has played. If the human response is too close to what GenJam just played, the chorus can "get stuck" on a lick that bounces between the performers until one or the other breaks the cycle with a fresh four.

In another form of collaboration the designer generates individuals and the system modifies them in interesting ways. When GenJam trades fours, it collaborates with the human performer in this way when it responds to what the human just played. The human plays a four, GenJam listens to it, mutates it and plays it back as a development of the human's four. This is a still deeper level of collaboration because the system is creatively manipulating the human's input.

The deepest level of collaboration is when the designer and system both manipulate each other's individuals in a cycle. This is a true partnership and approaches human collaboration among equals. GenJam reaches this level when trading fours. I find it at least as stimulating as any human I have encountered at the over 700 jam sessions in which I've participated over the years, and it is a more than worthy sideman. Besides, it always shows up on time and sober, and it doesn't rush the tempo!

3. GenJam is the Generative Jammer!

The requirements that jazz improvisation be spontaneous, original and collaborative make it a natural application of the generative design paradigm. In fact, I would argue that improvisation is the purest application of generative art to the musical world. In the case of GenJam, the "designer" is actually a fellow performer, which elevates the generative system's status to the same level as the designer because their collaboration is largely symmetric and their roles are essentially the same, at least during performance.

The conclusion, then, is that GenJam is a successful generative art system that supports a deep level of collaboration to perform jazz improvisation in real-time. GenJam's original interpretation as the Genetic Jammer is still valid, but it now also can be interpreted as the Generative Jammer!

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Computer Aided Evolutionary Architectural design

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Abstract.

The demand for sustainable low cost houses is increasing along with the technical demands imposed by national building code and regulations. The above outlined problems raise the following questions: 1) Is it possible to generate a draft from these initial design goals; 2) Can the same tool indicate what the best alternatives are; And 3) can the designer see what the consequence are of the design changes he makes. Goal of this research is to develop a design tool, based on an integral design strategy, with respect to engineering and spatial layout, which generates different dwelling layout concepts, 'optimised' to specific design goals.

1. Introduction

The demand for sustainable low costs houses is increasing and also the technical demands (building code and regulation) are increasing. The above outlined problems make us ask ourselves the following questions:

- Is it possible to develop a design tool, which predicts, the consequence of design- decisions;
- Can the same tool indicate what the best result is;
- Can the designer see what the consequence are of the changes he makes in the design;
- Is it possible to generate a draft with the initial design goals as start;

Goal of this research is to develop a design tool, based on an integral design strategy, with respect to engineering and spatial layout, which generates different building concepts, optimised to specific design goals.

Solving a multi-objective problem involves mostly several incommensurable and often competing objectives. Usually there is no single optimal solution but rather a set of alternative solutions. These are optimal in the wider sense that no other solutions in the search space are superior to them when all objectives are considered.

Its robustness and similarity with human design process is the reason we use a genetic algorithm to solve the multi-objective problem. Because of the 'nature' of the genetic algorithm, we have to code the building into an array of numbers, the so-called genotype. To implement the genetic algorithm in our tool we face an information problem. Is it possible to decode a string of (random) numbers into information, which tells us all we need to know how to "construct" the phenotype (= a building)? With "construct" we mean, make a 3D representation of the building, with all the used materials;

2. Design, a multi-objective problem

Before the architect can begin to design, he must inform himself about the 'client's brief'. In this document the owner/client states for instance the relationships between the rooms, the desired area of the rooms, the orientation, the location of the site, etc. After describing the requirements, the architect makes a first draft design. Then he has to evaluate the design in order to check if the building is designed according to the program of demands, the ruling national building codes (= objectives). If this is not the case the designer has to redesign his design. In most cases only a few 'items' are changed after the evaluation. This iterating process of designing-evaluating-designing goes on till the design meets all the objectives, and then the process is stopped.

The design process could be considered as a configuration problem. According to Lee et la [10] the **task** in configuration design is: to synthesize a system that performs the desired functions, meets the performance standards, and satisfies constraints, **given** some: functional requirements, performance goals and constraints. As Gauchel [4] conclude:

"Thus, building object can be thought of as systems, reacting on inputs, seeking stable, internal states or data levels, and having no outputs."

If we see a building as a collection of objects, we can define the design process as a configuration-task. The following characterization is adapted from Mittal and Frayman, 1989:

"Given a fixed library of components, some specifications on functionality, performance, and costs, construct an artefact using these components that satisfies the specifications. The

artefact must obey either rules of interconnection of components, or rules on topology, or both."

"Optionally, a set of preference or optimisation criteria can be given. The artefact must conform to these criteria."

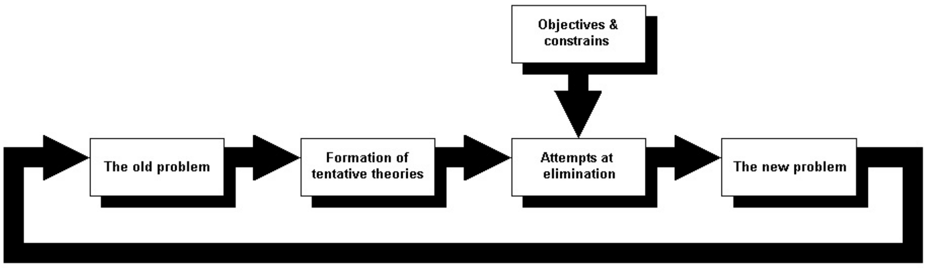


Figure 1 Design as multi objective problem

The consequence of this view is that the design process can be seen as the search for balance. In other words designing is the search for equilibrium in the design objectives. Simon [14] describes optimisation as follows:

"…The goals for adaptation of inner to outer environments are defined by a utility function- a function, usually scalar, of the command variables and environmental parameters- perhaps supplemented by a number of constraints (inequalities, say, between functions of the command variables and environmental parameters). The optimisation problem is to find an admissible set of values of the command variables, compatible with the constraints, that maximize the utility function for the given values of the environmental parameters."

3. Building Genome

The field of GA was founded in the early 1970's by John Holland who had the idea to try to solve difficult problems by allowing a solution to evolve - like nature does [6][7]. John Holland invented the traditional GAs (= Genetic Algorithm's) representing the chromosomes as bit strings and using operators adapted from nature for their reproduction. The term traditional GAs refers to the genetic algorithm in their initial form. That means bit strings as chromosomes; crossover and mutation as string operations; while the control parameters are static.

A genetic algorithm is started with a set of "solutions" (represented by chromosomes) called population. Chromosomes from one population are taken and manipulated to form a new population. This is motivated by a hope, that the new population will be better than the old one. Chromosomes that are selected to form new chromosomes (offspring) are selected according to their fitness - the higher the fitness, the more suitable they are and the more chances the chromosomes have to reproduce. This is repeated until some condition (for example number of generations or improvement of the best solution) is satisfied (see figure 2). Each chromosome in the final population is a coded solution for the problem [5][11][12].

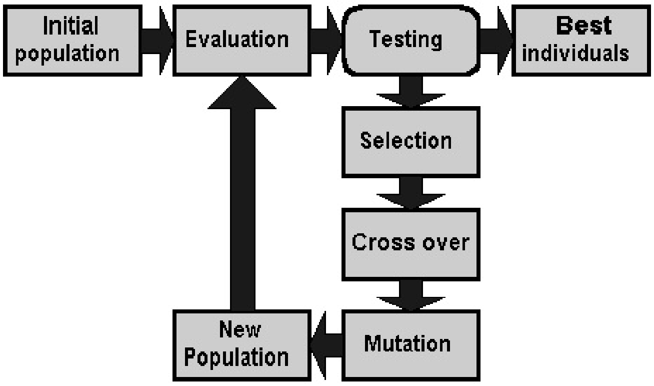


Figure 2 Process flow of a genetic algorithm

We can look at the algorithm as an intelligent search algorithm based on "trial and error". In this way we can compare it with the design process. If we can code a building into a string of number, there exists a mapping function between the genotype and phenotype. If we have this function we can use a GA as "designer" for our tool.

3.1 THE CHROMOSOMES

In nature DNA molecules store the necessary instructions for building a protein macromolecule. These instructions are copied from the DNA molecule into the form of an RNA molecule. Each of these RNA copies moves away from the DNA templates and enters the cytoplasm of the cell. Where they encounter the machinery that will convert the biological information (the instructions) into the correct linear sequence of amino acids that will become a functioning protein.

In our GA, the RNA-structure is sequence of integers. The genes that form the DNA-structure (written in specific alphabet, we use the binary) are decoded into a sequence of integer numbers. The RNA-structure is the building block of the phenotype, which makes the 'building-data-model'.

In the RNA-structure we recognize two types of chromosomes, enclosures-chromosomes and space-chromosomes. The first two chromosomes, in the RNA structure, represented two construction-types. Table 1 is a typical RNA-structure; with 2-construction chromosome and 4 space-chromosomes.

Con. 1				Con. 2				Space 1					Space 2					Space 3					Space 4				
1	2	1	4	3	5	2	7	1					3					5					7				

Table 1 The RNA-structure

In this research there is chosen for two types of construction namely, outer-walls and inner-walls. The after the construction chromosomes follow the space chromosomes.

3.1.1 Construction chromosome

The construction chromosome is made of several genes (see table 2). The "phenotype" translates these genes into material properties. Each gene stands for a product from the product dbase. A gene with the value of "10", corresponds to a set of physical properties, with rang number 10 in the product/material dbase. In return, this set of physical properties identifies a certain product or material in real life.

[00110000**0000**1010**0000**1010**1010**00000**1010]**

Material n	DNA	RNA		meaning	Material
	0011	3		Outer layer	Brick_2
	0000	0		1 layer	Cavity
	0000	0		2 layer	Cavity
	1010	10		3 layer	Insulation_3
	0000	0		4 layer	Cavity
	1010	10		5 layer	Insulation_3
	1010	10		6 layer	Insulation_3
	0000	0		7 layer	Cavity
	1010	10		Inner layer	Insulation_3

Table 2 The Construction Chromosome

The value is related to a specific set of material properties in a dBase. Each property set maps to a specific material or product in the real world.

	Name	D	Rc	σ	λ	ρ
1	Empty (cavity)		0.17			

2	Brick -1	0,10	0,250	2	0,4	800
3	Brick_2	0,10	0,167	2	0,6	800
4	Brick_2	0,10	0,333	2	0,6	800
5	Concrete_1			30	2	2300
6	Concrete_2			30	0,7	1600
7	Concrete_3			30	0,12	300
8	Insulation_1	0,07	2,19	0,0001	0,033	35
9	Insulation_2	0,08	2,38	0,0001	0,0,33	35
10	Insulation_3	0,12	3,57	0,0001	0,033	35
11	straw	0,75	8,33	0,0001	0,09	300

Table 3 The material dbase

3.1.2 Space chromosome

The space chromosomes stand for the rooms. The area of a room is coded as a rectangle. In table 4 a room is build up from 5 "genes", the first is decoded into the floor index, the next pair of genes correspond with the angle (ρ) and length (lt) of the (polar-) coordinate of the first corner. The next 2 numbers are decoded into the width and height of a rectangle. The coordinates of the 3 other corners are derived form from these numbers (see figure 3).

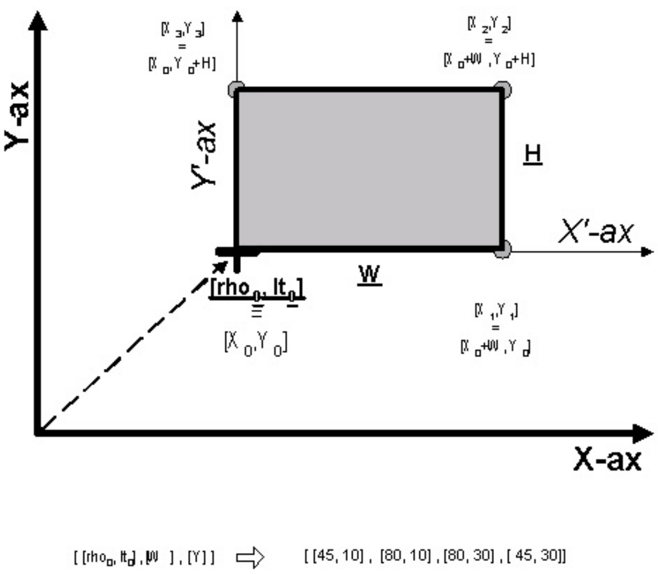


Figure 3 Transforming a rectangle into a array of integers

For the coordinate of the first corner of the rectangle is chosen for the polar notation, the reason is that with only positive numbers the whole x-y plane is covered.

[00110000**0000**1010**0000**1010**1010**0000**1010]**

	RNA	DNA	Meaning
Room n	3	0011	Floor index
	0	0000	X-point corner 1
	0	0000	Y-point corner 1
	10	1010	Width
	0	0000	Height

Table 4 The Space chromosome

Because of the nature of the GA it is possible that some floor/floor-spaces do not exists, say, we have a first, a third and a fifth floor. In the data model we reorganize the data in order to get a consistent model. In that case floors are renumbered to become consecutive.

3.2. EVALUATION

As we have seen, a genetic algorithm can handle only one fitness function, but a design problem is a multi objective problem. To over come this gap, we have to map the set of objectives onto a single number.

A feasible solution of a multi-objective programming problem is non-inferior if there exists no other feasible solution that will yield an improvement in one objective without causing degradation in at least one other objective. The idea of non-inferiority is very similar tot the concept of dominance. Some mathematical programmers call non-inferiority non-dominance, “efficiency” by others and by statisticians and economists, and “Pareto optimality” by welfare economists. In genetic algorithm research the term “Pareto-optimality” is mostly used, because of its definition:

"A social state is Pareto-optimal if no **individual** can be made better off, without making at least one **individual** worse off" [3].

The Pareto-optimal set can contain a large number of “solutions” to the problem. These ‘solutions’ are alternative solutions to a given design problem.

3.3. OBJECTIVES

We can categorize the objectives, which must be fulfilled by the design, into categories. Each of these groups consists of several criteria. For each group it is possible to give an importance (=weight) according to the wishes of the designer.

Category	Goal

Situation	Minimize shadow casting on neighbor property.
	Minimize noise level on walls.
Layout	Satisfy the relationships between the rooms.
	Satisfy the area of the rooms.
Material	Maximize heat resistance of the walls.
	Minimize moisture vaporization inside the walls.
	Minimize thickness of the walls.
	Maximize load-bearing capacity.
	Maximize durability of the used materials.
Costs	Minimize energy consumption of the building
	Minimize monthly costs of the building

Table 5. The Objectives

The outcome of the layout generating process depends heavily on the objectives it must fulfil. If there are to many objectives the search space will be to small and it can't find a solution. If there are there too few objectives there will be too many possible answers. The list of objective in table 5 is not complete. In the next paragraphs we will discuss briefly the objectives.

3.2.1. Area objective

The objective for a given area of a room is not exact. There is a range in which the room area is still acceptable. Therefore the objective, which controls the area of the rooms, is broken into two parts. One objective controls the maximum area of the room and one controls the minimum area of the room.

Objective 1: $f(x) <=$ max Area of the room
Objective 2: $f(x) >=$ min Area of the room

The area between the maximum and minimum requirement has the greatest fitness, because there both objectives are at peak.

3.2.2. Relationship objective

As stated earlier the designer has a client's brief, which can consist of a "relation diagram". If between the rooms a relation exists, the two rooms must be adjacent, and two other rooms. So "relations" must be translated into a property, which the GA can handle. A GA can only maximize or minimize of fitness.

Two rooms have a relation with each other when there is a horizontal overlap of the two room shapes on the same floor. When there is no overlap the rooms have no relation with each other. The fitness function minimizes the distance between two rooms if there is a "direct relation” between those rooms, or maximizes the distance between those rooms if there is “no direct relation”. An “indirect relation” is build up from two “direct relations” with the circulation room (not yet implemented). In future ‘releases’ the height of the circulations room will span more then one floor level, in order to have access to all rooms.

3.2.3. Glaser objective

A good designed wall doesn’t have any moisture evaporation inside the material layers of the wall. If and where in wall moisture evaporations occur, can be calculated with a so-called ‘Glaser-diagram’ [2]. The fitness function minimizes moisture vaporization inside the walls.

3.2.4. Energy performance index

According to the Dutch building law, a building has to fulfil performances. These performances have to be calculated according to rules, which has been development by the Dutch Normalisation Institute (Nederlands Normalistatie Instituut). NEN 5128 [13] gives the terminology and calculation methods of the energy performance of dwellings. The energy performance is a function of the total outside area of the enclosures, the heat resistance of the used material, window orientation and area, used heating installation etc.

The total energy performance of a building is expressed in the energy-performance-coefficient. This coefficient has to be less then 1.0 (for dwellings), the smaller the better the energy performance will be. It is our understanding that this objective will decrease the total area of the outside enclosure, and therefore 'making' the layout of the building less look like a pile of boxes. So we don't have to make an objective, which will decrease the outside enclosure area.

3.2.5. Costs objective

It is common practice to calculate the building-costs of a building is. But the big disadvantage of this practice is that there can't be a trade off between investments of increasing the energy-performance and the total costs of the building. Therefore we calculate the expected monthly costs of the building.

In this case investments in a better of the energy performance of the building by way of using a better isolation material or a thicker isolation layer in the wall, will decrease the monthly costs of the energy bill. If we don't look at the expected monthly costs, an investment wouldn't pay off; it will only increase the total building costs. There for we will reduce the monthly costs of the building, instead of the total costs of the building.

3.2.6. Shadow casting

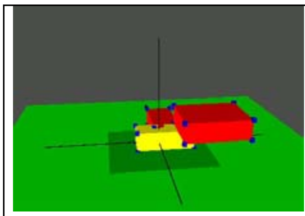
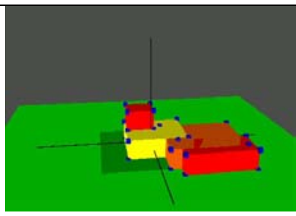
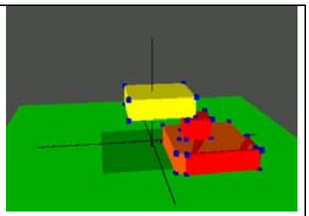
With the increase use of solar energy as a power source for heating, there will be also an increase in building on sites where the sun is not blocked by adjacent buildings.

The constraint “a building may not block solar ray’s from reaching the adjacent building” follows naturally from this argument. So the building to be designed may only casts a shadow on it own site. This requirement has a sustainability motivation as well as a legal. The building may not block solar ray because the neighbour building must also has the opportunity to use solar energy. According to Dutch Civil law the owner of a yard may not harass the owner(s) of other yards by rumours, trembling, smell, smoke or gasses or obtain **light** or air.

Because of the tendency of using more solar energy in the future it is to our opinion bad practice to design building, which cast shadow on the neighbour properties. In other words the building must be inside the so-called 'solar envelop' [9]. A 'solar envelope' is the maximum volume, which doesn't cast shadow on given area. This volume depends on the shape and the orientation of the situation.

4. Implementation

In our current system implementation we have used only the 'relation objective' and the 'area objectives'. The following images (see picture 4) show the outcome at some time during one run of the GA.

		
Fitness 0.026305	Fitness 0.961695	Fitness 0.961112

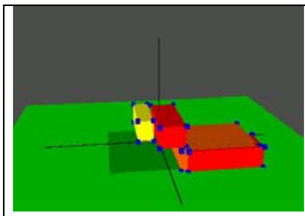
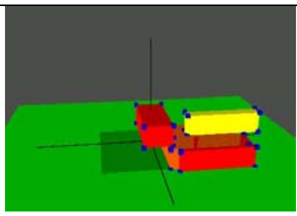
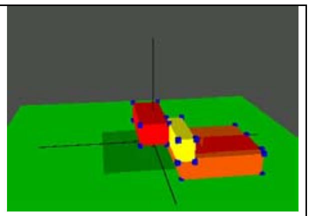
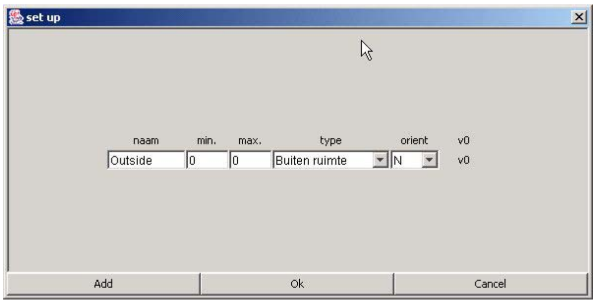
		
Fitness 0.900165	Fitness 0.912840	Fitness 0.95595

Figure 4 Examples

Requirements used by the example:

Client's brief (see picture 6a and 6b), in this dialog the user can add room. For each room a minimum and maximum area, room type and orientation is asked. As new rooms are added, relationships with the former rooms can be expressed, by pushing "tri-state" buttons. One click on the button result in a green icon on the button, two clicks on the buttons result in a yellow icon on the button and three clicks result in a red icon (the initial state of the button). A "red button" means "no relation", a "green button" means a "direct relation" and a "yellow button" means an "indirect" relation between rooms.



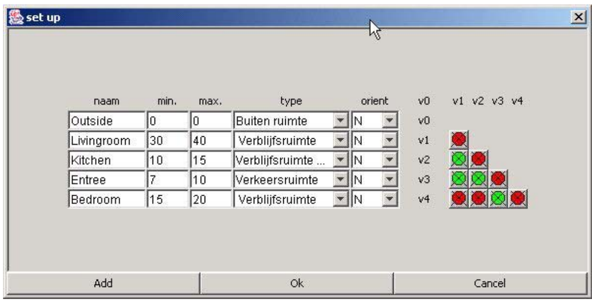


Figure 6a Client's brief (initial state) **Figure 6b Client's brief**

5. Further research

We have to implement more objectives in order to get a more building like outcome, as we have now a collection of piled boxes. Further research has to be done to implement windows into the model. The problem with windows is that it is not known in which wall a window must come and how tall it must be. This has rather a big influence on the genotype.

Secondly we will implement a way to manipulate the process, by selection or be weighted of some alternatives (see picture 7), in order to give those 'building' a bigger chance to propagate through the population. Therefore we have to find a way to find alternative designs in the whole population.

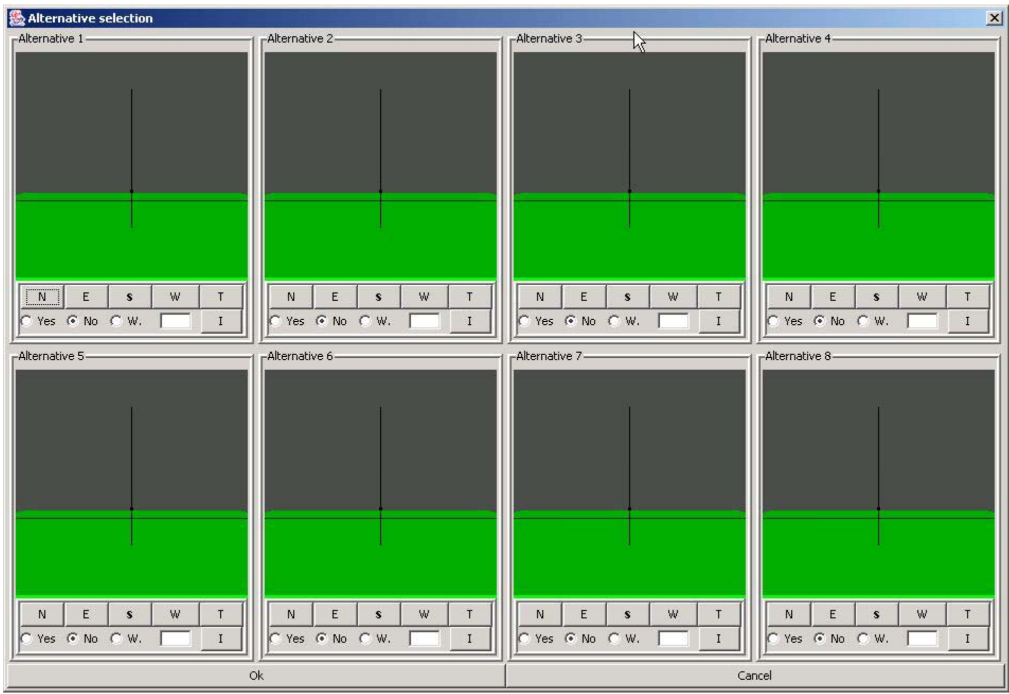


Figure 7 Alternatives dialog

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Computation-Universal Voxel Automata as Material for Generative Design Education

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Abstract

This paper is a report on the educational application of a voxel automata system for massively parallel execution of computation-universal cellular units in the generative design field. The software, designed and co-developed by the author to enable developmental strategies in generative design - for example with respect to 3D design generation, semantic self-evaluation and self-replication - was applied in teaching at the School of Design at The Hong Kong Polytechnic University to achieve two goals: to teach programming as part of the School's Interactive Systems Design stream and to teach generative concepts at a theoretical, yet hands-on and highly intensive level. An introduction to the software, its development and its functions as well as a discussion of the teaching/learning experience is given, highlighting design educational aspects and student design work. The paper concludes with an analysis of how student approaches to generative concepts have been affected by the tool and how ideas and feedback from students have supported the ongoing development of the voxel automata system and its documentation.

1. Generative Design as Interactive Systems Design

As part of the Hong Kong Polytechnic University School of Design's initiative in Interactive Systems Design, its 2nd year BA (Hons) design students have the opportunity to participate in a four-week project on Generative Design in the form of a profession-specific subject. These subjects, within the interdisciplinary BA (Hons) programme, are primarily intended to provide skill-based, technical training to complement the programme's cross-disciplinary, experience- and communication-focused elements. The teaching subject at issue (led by the author) provides skill-based training in basic programming techniques within the framework of a general introduction to Generative Design. This framework is used as an explorative context for programming experimentation. Together with the School's initiatives in the areas of design learning *by means of digital tools* (see for instance [6]) and design learning *about digital tools*, the Generative Design subject represents an example of the School's interest in communicating strategies of *designing (through) digital design tools* (see [7]). In this context, students are given the opportunity to study not only the application of design tools and methods but also the development of their own design tools and methods, understanding design as *toolmaking* (see [2]). Students are encouraged to consider computers not only as a *subject* of design, but also as *means* and *material* for design. Embracing skill-based technical training and conceptual generative design exploration, the teaching rationale of this subject is a strongly constructivist one, capitalising on student initiative, individual interest and prior knowledge. The implicit aim of "generative" processes of comprehension was discussed in the context of Generative Learning theory [18] in [9].

The Generative Design subject described above has been taught twice so far in fall of 2001 and again in fall of 2002, and each time it was attended by four students. After focusing on techniques of Java 2D graphics generation in fall of 2001, the class discussed here was designed to allow for more spatial experimentation, using an easier and quicker-to-learn programming technology. This was achieved by applying the voxel automata system *Zellkalkül*, of which a detailed technical account is given in the following section.

2. Voxel Automata for Digital Morphogenesis

Originally developed as a framework for experimentation in digital morphogenesis research (see [7]), *Zellkalkül* is a stand-alone Java application with a graphical user interface to a boundless 3D voxel automata system. The system is based on a Cartesian coordinate system to address close-packed voxels, which can be displayed either as spheres or as rhombic dodecahedra (compare [17], p. 544 ff.).

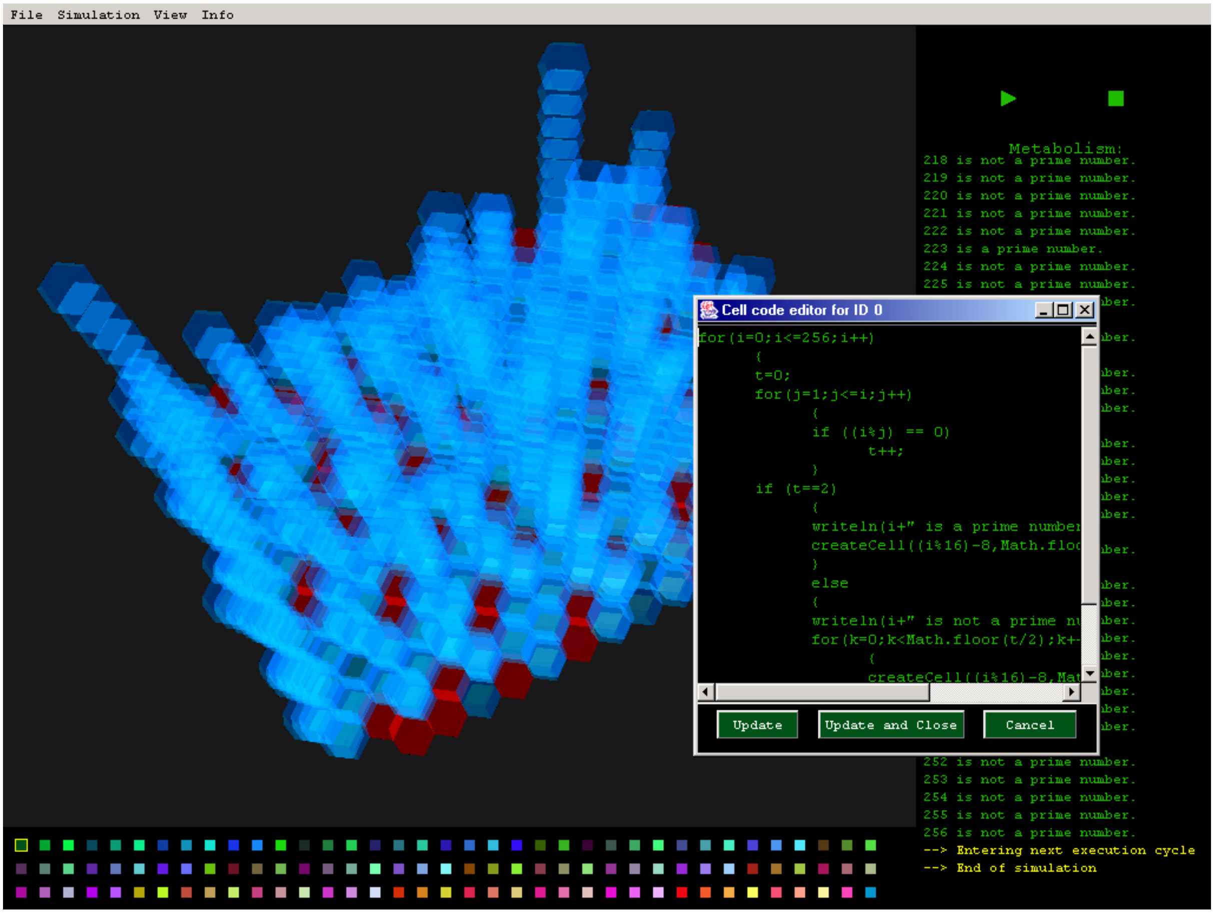

Figure 1: *Zellkalkül* user interface showing an example program/form

Zellkalkül's concept is based on principles of cellular automata and artificial life The three main differences between classic Cellular Automata systems and *Zellkalkül* are:

- *Zellkalkül* is three-dimensional and every cell has 12 neighbours.

- Its coordinate system is a boundless "universe" rather than a closed torus topology.
- Different cells in *Zellkalkül* can be governed by different behavioural patterns ("non-uniform automata").

The behaviour of cells in *Zellkalkül* is not limited by simple rules. It can be of any degree of complexity since *Zellkalkül*'s cells are freely programmable. This environment allows textual programming of cells to generate cellular manifestations of formal and/or behavioural character. Structures generated in the system can be picked and moved, rotated and zoomed in and out using the mouse and the cell's transparency can be globally controlled in ten gradients from highly transparent to opaque.

Voxels can have one of a number of identities (IDs), which are represented as coloured squares at the bottom of the graphical user interface shown in figure 1. Programming code can be associated with each ID. This code will define the behaviour of all cells that are instances of the respective ID during execution of the automata system. This allows the massively parallel execution of different code scripts in one automata system.

The programming language used is an extended version of ECMAScript [15], of which JavaScript and Flash ActionScript are descendants (Jean-Marc Lugrin's free FESI interpreter [14] was used). The language was extended by adding problem-centred elements for cellular morphogenesis including functions to create, inspect, manipulate and delete cells, as well as by provisions for intercellular communication and for parallel execution control. The functions allow basic operations ("create cell", "delete cell") as well as operations based on natural cellular paradigms ("split", "die"). These language extensions, the voxel coordinate system and programming examples are covered in detail in a system handbook [8]. Both procedural and object-oriented programming are supported by the scripting language. The system is designed to support endless execution loops, like those that occur life-game type cellular automata. During each execution cycle, each cell can execute either its entire code or a defined (special-character-delimited) segment of it. The runtime model is also borrowed from life-game-type cellular automata systems. It does not terminate after all cells have executed their rule-based behaviours but keeps on looping indefinitely. However, cells can be explicitly excluded from and included in execution cycles with code respective functions. Once all cells are excluded from execution, a cellular program terminates.

As a tool for 3D shape and behaviour generation, *Zellkalkül* has similarities to, but also significant differences from other voxel software systems. Kai Strehlke has developed an online collaborative 3D modelling and shape morphing system named "xWorlds" and applied it in design teaching for example at the School of Design at The Hong Kong Polytechnic University (see [16]). XWorlds' shape development is based on direct user manipulation and morphing techniques, and its parametric voxel-topology is based on cubic close-packing. In contrast to the three-dimensional educational (cubic) voxel modelling system DDDoolz [1] for example, *Zellkalkül* does not allow for manual (cursor-based) shape assembly. All form is generated by means of (multi)cellular programming. Compared to the three-dimensional environment for self-reproducing programmes described by Ebner [5], *Zellkalkül* is topologically based on close-packed spheres, each of which has twelve neighbours and it allows for higher-level cellular programming.

The program has undergone a number of different stages during its 10 months of (ongoing) development. It was inspired by observations made during the implementation and application of a haptic programming environment (this aspect of the project background was discussed in [7]). But being also inspired by classic cellular automata systems, it bagan with a two-dimensional grid with all the topological features of a Game of Life system (upper left side in figure 2). At this stage, manual tissue composition was possible. Very soon, however, the limitations of a two-dimensional system became too dominant and a mock-up of a 3D alternative was created for discussion (upper right side in figure 2). Note that at this and all later stages shown in figure 2, a 3D-cursor and cursor-control buttons for manual cell assembly has still been envisioned. This approach was later abandoned in favour of purely code-driven manipulation. Following a suggestion by Prof. John Frazer, the cubical voxel arrangement was abandoned in favour of rhombic dodecahedra. Based on extensive previous experiments and applications with this topology (see for example [10], pp. 84 ff. and 98 ff.), Prof. Frazer's advice has helped in avoiding the problem of having two types of neighbouring relationships and distances between cubic voxels (side neighbours and point neighbours). It was also key to the author's (and successively the students') understanding of how cells in such a configuration could be easily addressed (see further below). The rhombic dodecahedron is a comparatively "natural" form and was identified and described as a common natural cell geometry as early as in 1815 (see [12]).

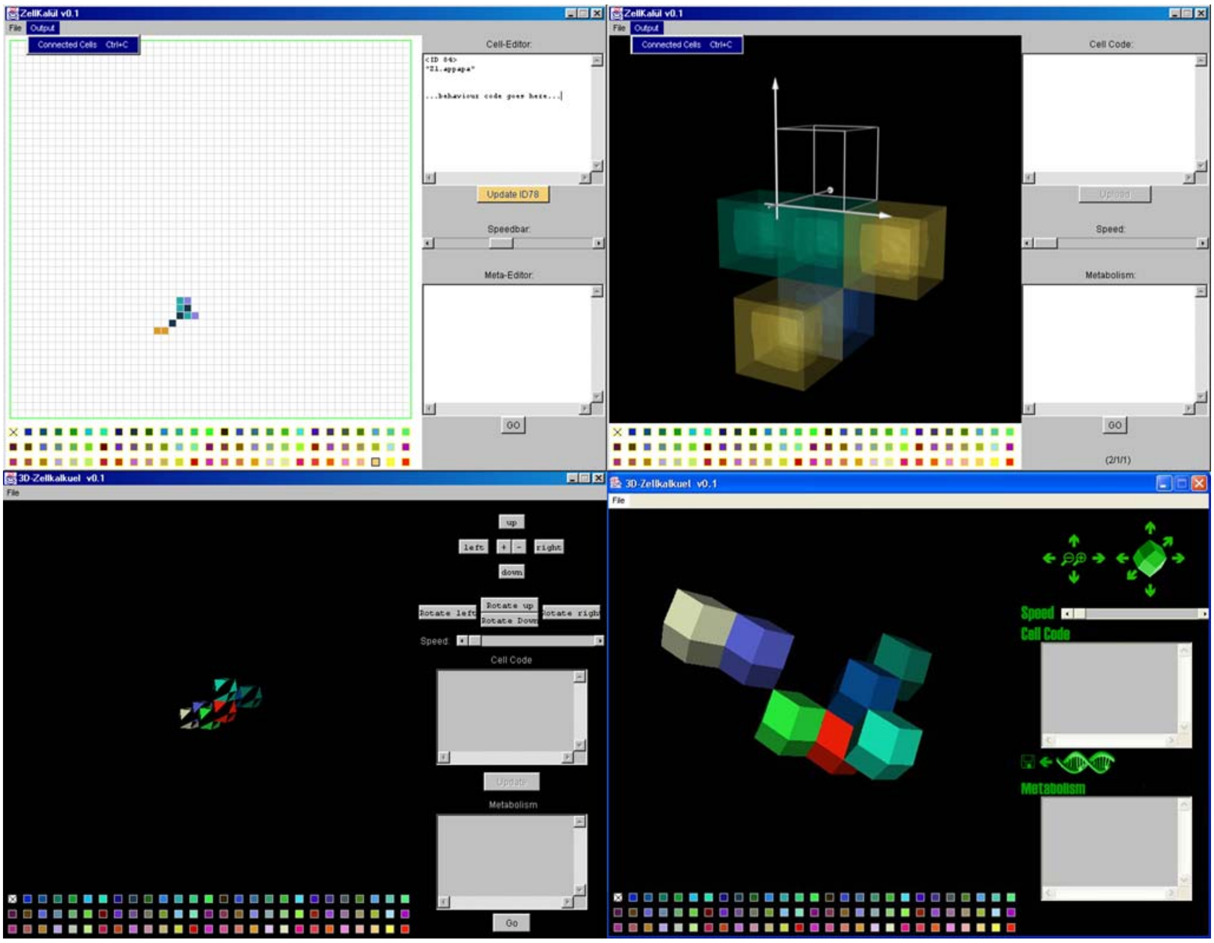

Figure 2: Evolution in *Zellkalkül* software development

The software represents an attempt to allow modelling of groups or colonies of parallel objects or particles (cells, atoms, molecules, planets, insects etc.) and nested systems of such groups in a very generic (application non-specific) manner. It is designed to potentially allow the simulation of any process of energy and material distribution/interaction in time and space, based on temporal and spatial relationships as well as on internal (programmed) logic. In previous research applications, *Zellkalkül* has been used to simulate cellular development in biological organisms based on temporal and spatial cellular identity (see [7], pp. 118-121). In other research contexts it is currently being used to investigate the possibilities of applying natural principles of morphogenesis to man-made design and construction. *Zellkalkül*'s development is ongoing, and planned future extensions include networked computation support by server clusters and parametric control of cell geometries to enhance the degree of freedom in form generation. It is also planned to make use of these new features in future educational design applications.

3. Generative Design Learning

As mentioned above, this subject preceded a previous four-week Generative Design subject taught in 2001 (also led by the author) that made use of Java2D technology to generate different types of line drawings (variations on replacement systems/grammars, space-filling curves etc.). The 2001 learning and teaching experience suggested the use of an easier coding technology and more interesting design representations than two-dimensional line drawings in the 2002 follow-up subject. This led to the decision to apply the research tool *Zellkalkül* with its 3D view and ECMAScript coding technology to Generative Design teaching. This has, however, necessitated the introduction of a number of new, abstract and harder-to-understand concepts to the taught subject, such as massively parallel programming, morphogenesis based on cellular development and a variation of the Cartesian coordinate system that is neither commonly known nor easily understood. The following example illustrates how such abstract new subject matters were introduced in quick succession using concrete examples and tangible teaching materials.

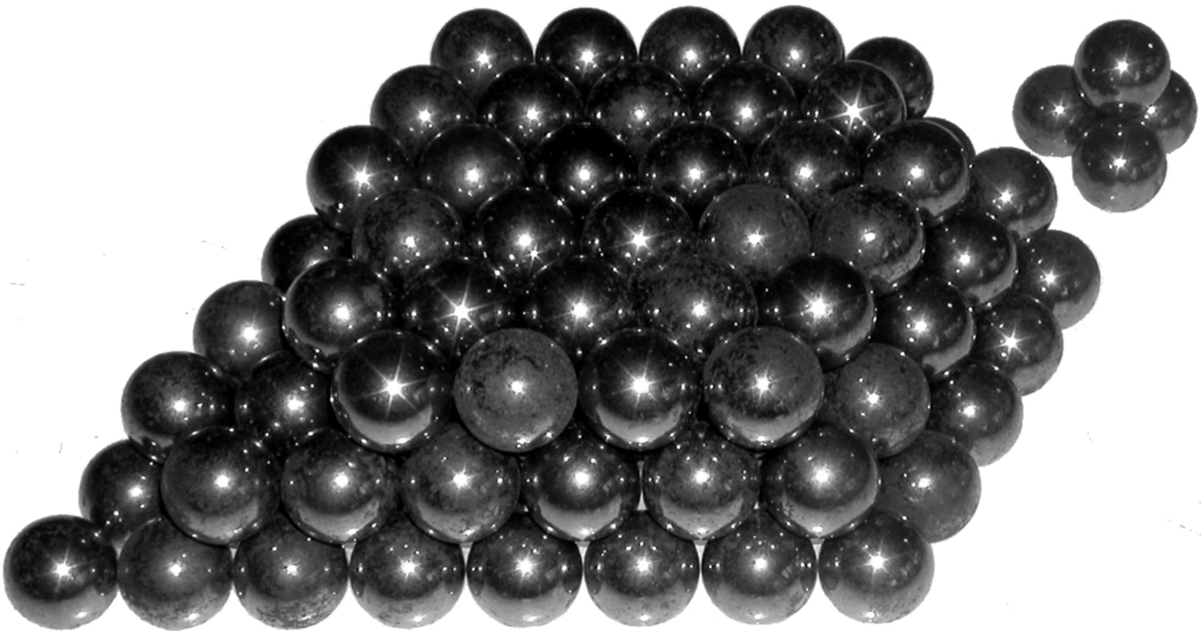

Figure 3: Physical models as learning aids: Ball bearing

Close-packed rhombic dodecahedra are arranged like spheres in hexagonal close packing (e.g. in face-centred cubic packing). Thompson gives an account on the relationship between spherical and rhombo-dodecahedral close packing on p. 552 in [17]. Figure 3 shows one of a number of ball bearing boards used at the School of Design's Design Technology Research Centre (DTRC) in close-packing related projects. The boards were used in this teaching subject to allow hands-on close packing experiments. The experiments (see image above) show that, unlike cubic close packing, hexagonal close packing places every layer's elements above the gaps between the elements on the layer beneath it. Elements are hence not stacked in straight (cubic) lines in all three dimensions which suggests at first glance that they could not be addressed in a straight-forward way using natural numbers as x, y and z coordinates.

The rapid prototype model shown twice in figure 4 (also produced by the DTRC), however, shows, that such a mode of addressing is still possible. The model on the left shows a sphere with its twelve hexagonally close-packed neighbours. Rotating it 60° to the orientation shown on the right reveals that this arrangement has strong cubic characteristics. This rotation is the single difference between hexagonal and face-centred cubic close packing. After the rotation, on each of the three horizontal layers, all elements are arranged along straight lines in both dimensions on the horizontal plane. The deviation from cubic close packing is an offset that applies to all odd-numbered layers, which also has the result that the vertical distance between two layers is not the diameter of one element but the half of the square root of one element. This illustrates how each element can be addressed using natural numbers as x, y and z coordinates in a Cartesian coordinate system if the described offsets are taken into account when representing the structure. *Zellkalkül* uses a simple Cartesian coordinate system and addresses based on natural numbers in exactly this way. Though this possibility might not be immediately obvious, it could be explained and demonstrated to the students within a matter of minutes using these tangible models.

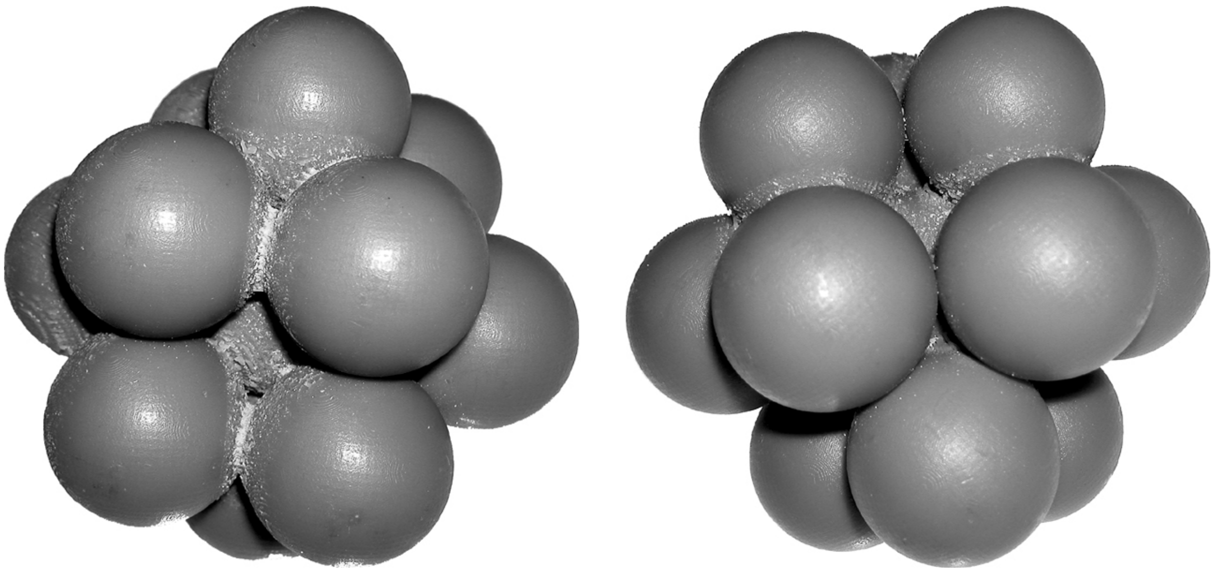

Figure 4: Physical models as learning aids: Rapid-prototype

From the author's and the students' perspective, it would have been highly desirable to be able to output structures generated in *Zellkalkül* on rapid prototyping machines. Unfortunately, while paying great attention to 3D data import, the Java(3D) development community has not yet provided a self-contained free solution for outputting Java3D data (*Zellkalkül*'s internal data format) as common 3D data formats such as .3ds or .stl. At this writing, an attempt to develop this possibility for *Zellkalkül* is being undertaken but could not be offered to the students of this subject.

As stated above, a code interpreter is associated with each of the spherical or rhombo-dodecahedral elements. Since the cell scripting language used is closely related to popular Web scripting languages such as JavaScript, JScript and Flash ActionScript, students were enabled to reapply their learned programming experience in later interactive Web design projects. To facilitate online code sharing and discussion, a "project hub" website was put online containing links to the *Zellkalkül* Handbook [8], Email links to all class participants and links to all project/data sharing folders of all class participants. These project and data sharing folders were set up on a departmental data storage and exchange server cluster for design teaching to which all students and staff have access (see [3]). The project hub website itself was used as a demonstration of how learned scripting knowledge could be reapplied in on-line authoring. It was based on JavaScript-based dynamic HTML, generated by code elements previously discussed in this subject. An analysis of the website's source code was used to re-iterate previously acquired programming knowledge.

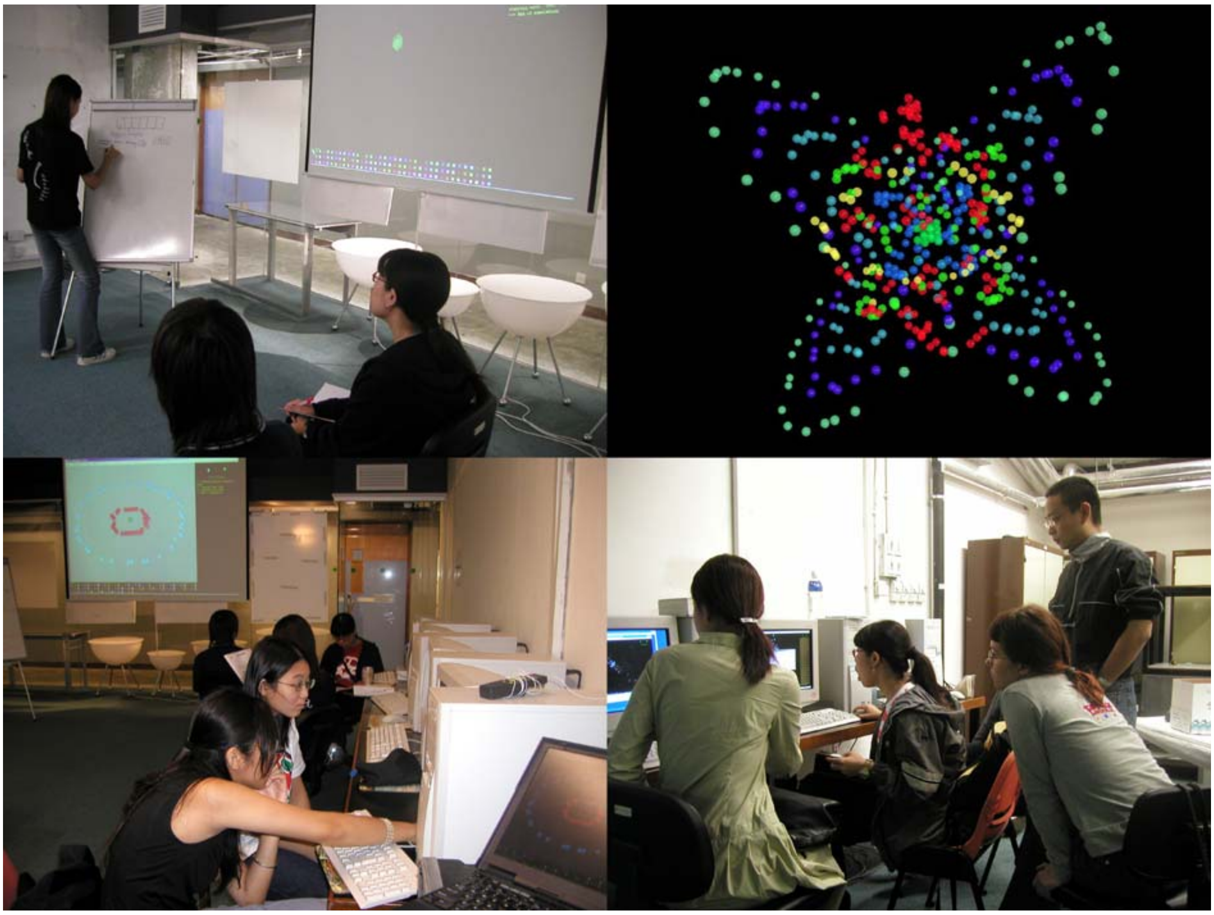

Figure 5: *Zellkalkül* coding exercises at the School of Design

In order to engage students in programming learning at a very high degree of activity and also to allow them to quickly achieve confidence in software development terminology, students were asked to research, prepare and deliver short presentations on programming language elements and to discuss related examples (variables and arrays, functions, objects, different loop types, conditional branching, etc.). Consequently, individual students became "experts" in particular code constructs and data structures, which was then used to build up a mutual programming support system amongst the group of students.

Since this subject focused on skill (programming) learning rather than on the production of design output of some kind, emphasis was put on the student's learning and thinking processes, their interaction and mutual support, which had to be closely observed and analysed. In order to allow such observation, the School of Design makes wide use of the "lablog" concept. Barbara Dass and John Frazer coined the term "lablog" in 1991. It refers to a combination of a laboratory notebook and a ship's logbook of a journey of discovery (see [4], p. 2) and describes a very free format for creating learning process/progress protocols. At the School of Design, lablogs are most frequently produced in form of A5, A4 or A3-sized notebooks or bound paper collections containing notes in various formats such as text, images, drawings, polaroid pictures, origami experiments, news clippings and so forth. These documents are typically reviewed together with students in tutorials during a subject and collected and analysed at the end of a subject for assessment purposes. Figure 6 shows an example page of one of the lablogs produced in this Generative Design subject: a reflection on how loop structures and trigonometric functions can be used to create elliptical and line structures with parametric variations based on the day (numerical date) of program execution.

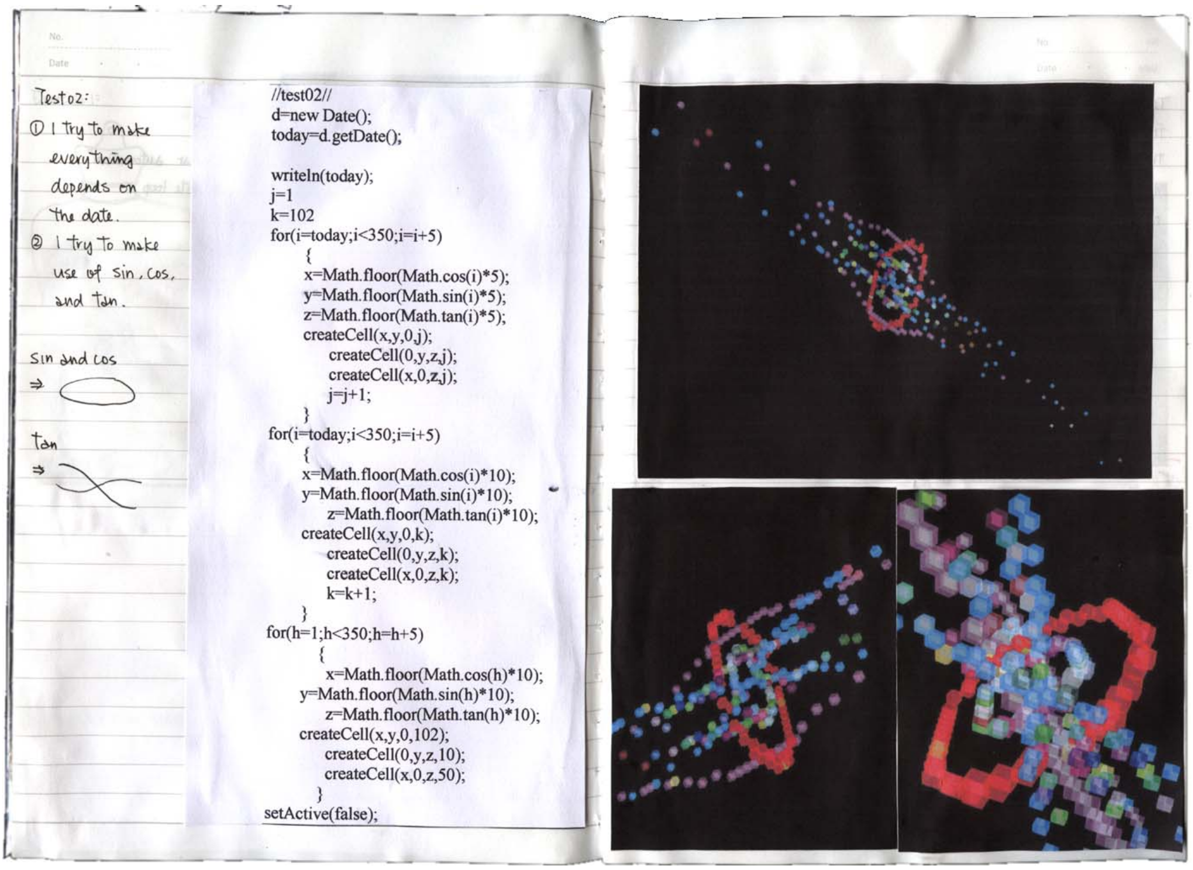

Figure 6: "Lablog" showing programming experimentation

In this subject, generative systems were represented as verbally described ideas, programming code, written text, sketches, virtual models of different types, screen shots and collaged lablog reflections. This multi-modal representation of concepts in this subject has led to a very intense learning experience.

Surprisingly, though the software used allows the generation of any kind of cellular pattern and though natural tissues typically consist of solidly close-packed cells, the students in this subject showed great interest in very loose, line and surface-type configurations. One reason for this might be that, despite adjustable cell transparency, it is rather difficult to visually understand the inner structure of solid configurations, which is made more difficult by the large number of faces at different angles in different layers when viewing cells as rhombic dodecahedra. By generating loose and rather sparse structures, students achieved configurations that were very easily comprehensible on the two-dimensional screen by moving and rotating them. Accordingly, students developed a strong interest in line, curve and circle drawing algorithms rather than in control structures that are more suitable to fill space solidly. Before this subject the students had little or no previous programming experience. Because of this lack of preconception, it was expected that they would unquestioningly embrace the massively parallel programming paradigm. Nevertheless, they tended strongly towards structures developing from code in one single cell and terminating this program after the first execution cycle instead of programming multiple cells using intercellular code manipulation and communication or repeating execution cycles. One reason for this might be the simplicity and sequential linearity of most programming examples in the *Zellkalkül* handbook at that time. The software, many of its code functions and the handbook were further developed over the course of the subject to reflect emerging problems and ongoing discussions. The mentioned tendency of the students led to an emphasis on multicellular programming and runtime coordination in successive additions to the handbook, and to the incorporation of more code functions for runtime management. However, this did not change the students' bias towards procedural coding executed as single-cell programmes.

4. Conclusion

The teaching subject discussed above demonstrates a successful application of research tools to learning and teaching. It succeeded not only in making efficient multiple use of a software development project but also to make students aware of some present-day design research approaches and tools. Up to this point, experimentation in *Zellkalkül* has tended towards abstract and rather sketchy results. Since the discussed subject was more process-centred than product centred, this was not seen as a problem and it has helped to avoid overly iconic "3D drawing". Understanding the software and in particular its coordinate system poses some challenges for learning and teaching especially in a very short subject. But using tangible learning materials and encouraging mutual student support have proven to be very effective in this context. In general, this subject and its outcomes have been regarded as more interesting, and its learning has been experienced as more effective and worthwhile than in the previous Generative Design subject in 2001 using Java2D. In this subject, mainly due to time constraints, only a small fraction of the versatility and power of *Zellkalkül* was made use of by the students. It became obvious that this research tool could serve as a learning environment for much longer and more intense teaching subjects and experiments in the Generative Design field. It is planned to expose students to *Zellkalkül* for longer durations in the future. The use of the programme by users without previous programming knowledge, who can take a fresh view at it, is expected to continue to drive the further development of this research tool, its applications and its documentation.

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Pursuing New Urban Living Environment In The New Millennium: Projecting The Future Of High-Rise And High Density Living In Hong Kong

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Abstract

High-rise and high density living is a way of life for most of the 6.7 Million population of Hong Kong. The merits and demerits affiliated with Hong Kong's compact urban form continues to attract academic deliberations and debates over the acceptability of such urban form as an alternative to urban sprawl for future city and urban life-style.

This paper traces the development and causes for Hong Kong's high-rise and high-density urban form over the past fifty years or so, and focuses its discussions on the pros and cons of high-rise living based on subjective user survey in late 2001 and early 2002.

Because of an articulated land shortage, acute topography, escalating population growth, and shortage of time, Hong Kong government and planners have little options left but to adopt vertical development, resulted in a densely and mixed use urban habitat packed with closely built high-rise residences and commercial buildings. From the survey, it is clear that mixed and intensive land use, high quality of living and recreation infrastructure, efficient public

transportation network, and segregation of pedestrian and traffic can facilitate the performance of compact urban form. In addition, most of Hong Kong families have been accustomed to high-rise living pattern and the disadvantages such living pattern might cause on its resident's social communication and children education are readily ignored by most of the people.

Based on the analysis of current living situation and development trends in Hong Kong, new pattern of future city form is conceived to be a likely applicable development way in a coastal city with such high density as Hong Kong in the next 50 years. Design countermeasures are presented in this paper to suggest ways of alleviating the pressure of the forever-increasing house requirements in Hong Kong.

Keywords: high-density, high-rise, compact city, social acceptance, life-style.

Introduction

Hong Kong represents a singular case of its own. Hong Kong is unique because it represents an extreme case of overcrowding, escalating population growth, scarcity of land resource, intensification of land-use activities, burdened by an absence of raw materials and natural resources. Yet, the story of Hong Kong as a Sky City attracts wide interest from urban designers and urban managers to acquire clues to successful managing of limited resources, and more importantly the ways to maintain a vibrant and rich living and working culture in a vertical land use approach, the vertical dimension of which astonish the world at large.

However, it is not just the height of buildings that is staggering but what is dramatic is the density of the city as a result of an enhanced plot ratio (Table 1).

Today, Hong Kong has an average density of 6,310-person per square kilometer and a peak urban density of 44,210 people per square kilometer that is among the top in the World. But what matters most, however, is the underlying phenomenon, which brought success for such compact city, as Hong Kong manages to keep its inhabitants relatively cheerful and healthy, letting most of them to enjoy short travels from home to work, enjoy leisure and spare time, and most of all, enjoy the glittering glamour of city life as a whole.

The aim of the paper is to present an academic critique on high-rise, high-density urban form found in Hong Kong as an alternative solution to future urban form, based on empirical data and field survey.

Background

Population, Land and Resources

Hong Kong has continuous problems of land scarcity and increasing population (Table 2, 3). The fact that only 21.1% of Hong Kong's land area is built-up imposes tremendous pressure on the incessant need to house increased number of people. Hong Kong is one of the world's densely populated cities (Mongkok and Kwun Tong are two localities which exhibit extreme density).

Shortage of land and increasing population has been a major cause for a high-rise and high density Hong Kong. Over 50% of its 6.7 million population (mid-2001 figure) live and work in urban centers, Hong Kong Island and Kowloon, for convenience and efficiency that proliferates the intensification of human activities within urban centers. Latest government census in 2001 reveals that about three million people live in self-owned private homes in high-rise apartment blocks. This is translated into a total of one million numbers of private homes. The rest of the population lives in, similarly, high-rise and high-density rented homes in new towns in suburban Hong Kong known as the New Territories[1].

Socially, Hong Kong population is made up of primarily immigrants from different provinces of Mainland China. To date, the influx is as much as 150 numbers of legal immigrants daily. This seemingly small figure is actually a prime contributor to the population increase of one million every decade as recorded throughout the past decades, with the first generation of immigrants from the Mainland China arriving in early Nineteen Sixties. Thus, the immigrant society

[1] http://info.gov.hk/censtatd gives key data of Hong Kong based on the 2001 census.

continues to yield pressing demands for infrastructure and social supports of all sorts throughout the recent history of Hong Kong.

Hong Kong – Challenges

The Planning Department projected that the population of Hong Kong will continue to increase and will reach 7.5 million by 2011 (Figure 1). The challenge for the 21st Century is a complex one represented by several crucial factors.

For Hong Kong, the initial challenge is its ability to cope with changes. It begun with the 'July 1997 Handover', which staged an era of change for the ex-colony's governmental culture as well as administrative structure.

November 1997 brought a second wave of change to the economic structure for many Asian capital markets including that of Hong Kong. Ever since, Hong Kong suffered from record negative GDPs to an estimated +0.5% growth and an unemployment rate of 5.5% in 2001. The economic downturn since 1997 stubbornly prevails and becomes a chronic threat to social stability and social hierarchy, as disparity between the highest income group and that of the lowest income group tops Hong Kong on a recent Asian count. High land costs, which boosted property rent and sale price, together with high salaries, are guilty of being the blocking stones for economic recuperation.

Apart from economic and social challenges, environmental challenge became the third wave of change as awareness continues to escalate and motivate the general public much readily due to a hyperactive news media supported by similar world awareness in this topic. Rising community concern for the environment is a popular growing social concern in most cities around the world. Hong Kong is no exception. It is interesting, however, to differentiate that most members of the public are more concerned with the quality of life as indicated by the standard of living, costs of living, emerging lifestyles, etc. rather than the quality of the environment; though they do not easily see an inseparable connection between these two concerns, most citizens realize that environmental challenge has a strong impact on quality of life. Recently, the search for better quality of life becomes a subject of research for many cities, such as Tokyo, London and Hong Kong. The University of Hong Kong, for instance, initiated inter-city comparative studies of urban sustainability contributors such as density, lifestyle, and space usage[2].

Hong Kong definition of high-density and high-rise living

For Hong Kong, the multiple use of space and land use has a long history of practice. The use of multiple spaces is a unique character of Hong Kong; its definition, however, is blurred because it is responsive to changes in societal preferences that in turn are subject to changes over time.

Extendable space -- Concept of space borrowed

The author of the book 'Hong Kong borrowed place, in a borrowed time'[3] hinted a Hong Kong mentality for survival, which may be interpreted as an existence of uncertainty. The thought that one only remains in Hong Kong on a temporary basis, and sooner or later one would leave Hong Kong for good, to somewhere else for a better life, was a saddening but determined mindset for the 'temporary' settlers of Hong Kong. On a slightly different context, the discussion here may be referred to another facet of Hong Kong's transient way of life, where everything is too space-constraint and congested as to constitute a phobia, it became an irresistible need for many families to 'borrow' space whenever one feels the need (Figure 2). Some nicknamed such act of space-borrowed to be a self-help act of extendable space, practiced by countless number of local home dwellers, those who would 'extend' or 'borrow' a space out of metal cages and wooden floors added onto existing windows of living rooms and kitchens**.** For the law enforcers, these are better known as illegal space. But the concept of borrowed space does not necessarily be confined to the 'extended' living or dishwashing space. There is another category of 'borrowed'

[2] Since the fist international conference on Mega-cities was organized and held in the University of Hong Kong by the author in February 2000, the Center of Architecture & Urban Design for China and Hong Kong at the University has initiated and set up a research network between various researchers from cities interested. These are the city of Tokyo, Shanghai, Kuala Lumpur, Oxford, Eindhoven, Madrid, New York and Sao Paulo. The Mega-cities discussion will be staged in the Universidade de Sao Paulo, Brazil in October 2002.

[3] An infamous book by Hughes, the Far East Correspondent, on the future of Hong Kong with 1997 approaching. The book described Hong Kong Today, Hong Kong Yesterday, and Hong Kong Tomorrow. The sub-title 'Borrowed Place – Borrowed Time' is first used by writer Han Suyin in her article "Hong Kong's Ten-Year Miracle" published in Life (1959).

space in Hong Kong, which refers to the extension of social space by means of restaurants, coffee shops or street eating. In Hong Kong, where most apartment homes have a relatively small area, many families prefer to entertain their guests or friends in commercial places as an extension of their homes (Figure 3). In this way, the ‘borrowed’ space concept becomes a cross over of residential and commercial land use. As an extension of living spaces, restaurant becomes the dining room and the living room becomes Karaoke Lounge across the street. This is particularly true as one skim through the built-up city to see numerous MILU (Multiple and Intensive Land Use) buildings in residential areas. The overlapping, and mixing of functions in buildings make one became puzzled as to whether the building should be classified as commercial or residential or not.

Concept of space proximity

Density figures associated with population per square kilometers suggests that in Hong Kong, where built forms are close to each other, the physical and psychological interactions between spaces, between people, and ultimately between man and environment are often conflicting and unacceptable! For example, the two urban areas which exhibit a world record figures of over 40,000 populations per sq. Km suggests such habitable space to be ultra condensed and packed (Figure 4)!

On the contrary, field studies suggest that this lack of distance apart, or ill definition of territorial space is, for most locals, a natural way of life that exists almost as old as the city itself. More interestingly, such closeness in space does not necessarily lead to uneasiness for the inhabitants, as one would expect from textbooks on urban space (Lau survey 2001)[4].

Concept of Cultural Adaptation and sharing

[4] This is a 9-month research survey carried out by the author on subjective responses of households towards various aspects of high-rise living. A total of 102 families in Hong Kong was interviewed and asked about their opinion towards the pros and cons of high-rise living. Of the 102 surveyed, 98 households enjoyed high-rise living as an acceptable form of urban living.

As suggested, in the case of Hong Kong, space proximity is taken as a tolerable way of life rather than an acceptable spatial attribute. Field studies and survey[5] suggested that there is clear evidence that almost all residents prefer an improvement to their living area more than anything else.

Such observations from field studies and survey may be explained further by views collected from interviews with psychologists[6] who explained social acceptance for close proximity space by the concept of adaptation.

A Clinical Psychologist, Dr. Edmond Lau recalled that the Chinese have a long history of different families living in clans as in the Wu-tung Courtyard Houses found in Beijing, Lei-Long Houses in Shanghai, or the Walled Villages (Wai Cheun) of the New Territories, Hong Kong. Indeed there is an analogy with most other human settlements throughout history of mankind for social and defense purposes. Yet, Dr. Lau gave another explanation towards the tolerance towards living in close proximity space. He thinks that Chinese have a long history of living with several generations under one roof. Effectively, this means the living-in of three generations comprising grandparents, parents, and children for social supports among the family members. Space sharing is a long adaptive act. In the eyes of the Psychologist, such practice of social bond gives rise to an adaptive act of space sharing for the local families, which is translated, into an acceptance for space proximity in a high-density environment.

Concept of Compactness

Hong Kong, where everything is so closely packed, is a perfect case of Compact City. Here one may find the intensification of land use and mixed use in majority of cases found in the urban centers. The Oxford Center of Sustainable Development pioneered the study of Compact Cities in an effort to map and analyze the making of and impacts of compact cities in both developed as well as developing cities. Researchers from different cities have been invited to document and

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[5] The development of satellite new towns in Hong Kong takes four phases. Which begun from 1959. They are Tsuen Wan, Shatin, Tuen Mun, Tai Po, Fan Ling and Sheung Shui, Yuen Long, Tseng Kwan O, Tin Shui Wai, Tung Chung and Tai O.

[6] Mr. Tony Wilson, Chief Architect, Architectural Services Department. Hong Kong Government presented his analysis of Hong Kong's city development by the 3C concept, at a joint HKU-ASD research presentation to the Technical University Berlin in Nov 2000.

analyze the contributors to a successful compact city based on Hong Kong. In this exercise, Hong Kong offered itself as a specimen for studying compact urban form because the city possesses most of the theoretical attributes of a Compact City - a urban system with high density, high floor-to-area ratio (plot ratio), mixed land use, short distancing and a multitude of inter-connected and efficient public transit system. A notable subject of study, however, is a measure of transport efficiency, expressed by the homework travel time measure. For Hong Kong, the average travel time between home and work ranges from 30 minutes to 45 minutes per journey, which compare comfortably with metropolis like Tokyo that has a 90 minutes or more per journey.

Concept of Verticality

The vertical city image of Hong Kong is portrayed by thousands of two hundred meters tall towers of residential apartments, or offices of similar heights. Recently, the projection of extending the Vertical City to 100 stories or 450 meters tall is no longer a dream but rather an imminent reality for urban practitioners. Vertical concentration means convenience and efficiency for the Hong Kong dwellers! The UN Statistics Year Book of 2000 adds that the vertical city of Hong Kong, where stacking floors on top of each other like sardines are actually one of the most energy efficient built form exists worldwide. A recent survey (conducted in 2001 and 2002 in Hong Kong) interviewed 102 number of residential households who live in private and self-owned apartment buildings reveal majority of whom likes to live on higher floors for the enjoyment of better views and fresh air more than anything else (such as monetary benefit being on a higher floor). The same survey also indicated the concern over damaging effect on the growing up of children who live their lives in high-rise apartments. Mothers are asked of the distancing and separation from the ground because of high-rise living. The reply represents that a significant support to high-rise compact living (Figure 5). Japanese Researcher has raised similar concerns to Japanese residents in 1993. As expected, there was a difference in the response and considerable reservation towards high-rise living due to particular concern of child's physical detachment from ground activities. The remedy, as observed by researchers working together from both Hong Kong and Japan is the sophisticated design of an artificial ground on a podium acting as a substitute of the ground, introduced as a common feature to high-rise residential towers.

Concept of Sky City

In Hong Kong, activities do not happen on ground alone, always, they happen above ground! In this multi-layered city of Hong Kong, all kinds of human activities have taken place on two or multi-levels, as seen in a multitude of double layered web-like network of pedestrians walkways crisscrossing in and out of buildings or over pedestrian pavements and over vehicular traffic roads in most commercial or residential areas of the city. The segregation of pedestrian and vehicular movements arise not from planning theories but from the necessity as there are too many people on too narrow pavements, outnumbered by cars (Figure 6).

For a long while the practice of sky city supports the physical growth of the city. Double-decker bus, double-decker ferry and double-decker tram, double level pedestrian system, double-decker footbridges, and even double-decker elevators all are exemplifiers of the concept of sky city! Added to that is the emergence of sky malls in some of the city's new commercial developments. As one architect remarked in his first visit to Hong Kong, almost all things happened on different levels other than the ground! This is a true 3-dimensional Sky City!

Development of High-density High-rise Living in Hong Kong: A way of spatial planning

Stage 1

Like a lot of cities, it started with the fusion of commerce and residential activities, with the classic layout of shop on ground floor with residence in the rear, or on first floor. In those early days of Southeast Asia, this type of development is named Shop House, with most of which designed and constructed for climatic responsiveness. When the city expanded, the 2-stories shop houses took little time to transform into multi-stories residences on top of multi-stories shop houses.

Stage 2

The first major deployment of the multiple use of space could be found in a mass private housing development in the early seventies.

Case Study 1: Mei Fu Shan Chuen development

The Mei Fu Shan Chuen (Figure 7) is the first conceptualization of high-density and high-rise urban design by way of modularized housing for Hong Kong. It was a phased private project, which started from 1969, completed in 1970, and followed by successive phases of expansion over the years until 1989. Mei Fu today has 117 towers of 15 stories tall apartment buildings crowding on four adjoining sites constituting a self-contained township for its 46,245 mid-income group of residents or 13,068 households living on a small but compacted urban site close to business and fiancé centers on both sides of the Harbor.

The development is a blown-up version of the shop on ground and residence on floors above, made practical by a coalition of land use functions on the ground and upper levels such as bus terminus, food markets, gardens, sports ground, cinema and shops, thus, making it a self-sufficient city (Figure 8)! Over a period of almost 2 decades, the former seaward petroleum fuel storage yard and jetty site of Mobil Company is transformed into a livable city by the sea. The Mei Fu (Chinese name translation of Mobil) Model soon became a model for many more to come in the following years.

Stage 3

The success of the Mei Fu Experiment has a lot of impact on the acceptance of high-rise and concentrated living by the populace as well as government planners and developers. What followed and flourished over the next decades were not a repetitive copy of the Mei Fu Model but instead a gradual advancement of a highly sophisticated self-sufficient and mixed land use concept that became a driving force for the next generation of multiple use of space. For sites which are much restrictive in areas, designers have no hesitation but to stack up the living and non-living activities in a vertical layout. What evolved are towers of multi-stories residential apartments sitting on top of a relatively big podium in which all ancillary facilities are found. The second-generation model i.e. the fully developed podium model became a refined MILU norm for the period from the nineteen eighties to present. Its emergences were supported by the amendment of the building controls statues, which sets the rules for a high-rise urban form (see table 1).

Case Study 2: Metro-City Residential Development, Tseng Kwan O New Town, Hong Kong

Tseng Kwan O (TKO) (Figure 9) is one of the 10 satellite towns[7] of Hong Kong. Being the latest addition to the new towns, it is separated from most parts of Hong Kong by an hour over journey (our survey shows that most people's commuting time from home to work in the Central District is 30 to 60 minutes, facilitated by an ultra-efficient public transportation system).

The town is built over the old site of Junk Bay – a seashore site for recycling steel parts and bodies from obsolete ocean vessels. Artificial land was created by massive reclamation achieved in a relatively short span of time, followed almost immediately by massive housing construction. Here one sees forests of bamboos shots-like apartment buildings popping up under the barking sun and monsoon breezes of the South Pacific seasons. The towers are as tall as 40 stories and more recently reaching 60 stories, making the town of TKO a showcase of extreme high-rise high-density livable urbanity.

For the TKO Metro-City Development, it took its shape to the fullest in three phases with occupation from May 1997 to April 2000.

Phase One contains 2,048 households or 6,700 residents in 6 towers of 43 stories tall. Phase two houses 11 towers of 38 stories tall, has 3,344 households or 13,376 residents. Phase three comprised of 4 towers of 43 stories tall buildings that have about 1,376 households or 5,600 residents.

What is significant about these towers is not their astonishing vertical scale, but rather an underlying guiding principle that governs the spatial and functional relationship resulted in hundreds of similar developments in TKO. Here, one finds a unique Hong Kong fixation of a MILU application on a relatively small land parcel that afforded a floor area ratio of 10 times the

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[7] The development of satellite new towns in Hong Kong takes four phases, which begun from 1959. They are Tsuen Wan, Shatin, Tuen Mun, Tai Po, Fan Ling and Sheung Shui, Yuen Long, Tseng Kwan O, Tin Shui Wai, Tung Chung and Tai O.

land area, realized by 21 towers of over forty stories tall which houses a total of 6,768 families or 9,600 population.

The unique feature of such MILU development is the fact that all of the residential super-high-rise towers sit on top of a 100% built over podium of 15 meters or 4 stories tall. In this case, the three phased developments are developed from three land parcels connected by 24 hours accessible covered walkways, and conveniently connected to the Mass Transit Railway.

On the bottom floor is a terminal for both long haul and local commuter buses, maxi-cabs and taxis. Next to the transport terminal are post office and food market and supermarket. Within the podium situates a two level car park for residents and shoppers. There is also a shopping mall, which improvises retail, food, entertainment and all kinds of supplies and goods outlets. On the roof is yet a different land use, comprised of landscaped park, playground, indoor and outdoor swimming pool, club house, tennis courts and jogging paths, all for the exclusive use by residents living in the towers above the podium.

The Metro-City case exhibits the art of connectivity as discussed in the concept of connectivity. The Metro-city podiums, like hundreds of other similar MILU podiums in the area, are connected with each other by covered walkways, making it in effect a connectable town of multiple layers.

It is interesting to note that the three developments have in fact their own podiums of shopping malls, shared clubhouses, car parks, and other recreational facilities.

The Survey

The author conducted a survey to investigate the subjective response of residents of high-rise, high-density living in Hong Kong. The survey was conducted in the period of September 2001to February 2002.

The objectives of the survey is summarized to be:

(1) To investigate users' responses towards high-rise living in existing residential buildings in Hong Kong that are mostly 30-40 stories high and constructed in the period of 1990s.

(2) To formulate underlying principles for social acceptance towards high-rise living in the Hong Kong context.

(3) To predict local social acceptance towards a high-rise living which is moving upwards and higher. The question in mind is 'Will Hong Kong residents accept to living in 100 stories and higher super-high-rise towers?'

(4) To compare with the findings of Japanese research on high-rise living in 1993.

At the end of the survey, a specimen of 100 families was surveyed. The specimen is considered adequate as they represented a wide range of different scenarios for the Hong Kong living environments, summarized as:

(a) Two-thirds (68%) of the specimen lives in different urban areas on Hong Kong Island and the Kowloon Peninsula, while one-third (32%) live in the new towns in the rural areas of mostly the hinterland to the north of Kowloon known as the New Territories.

(b) 99% of the families live on different floors of existing high-rise residential buildings, with an exception of one who live in a two stories village type house, which has been disregarded in the analysis.

(c) 36% of the families live on 25th Floor and above, with the remaining on different floors on high-rise buildings ranging from 15 stories to 43 stories overall.

(d) Majority families belong to the mid-income group (Table 4, Figure 10, 11). The randomly distribution of interviewed families gives the following breakdown – there is a small proportion of mid mid-income families with monthly family income ranging HK$30,000-50,000 (17 out of 100 families); a large proportion of well-off middle families receiving $50,000 and above (77 out of 100 families); and an insignificant proportion of the surveyed families (7 out of 100 families) that have a low income of around HK$20,000 per family. [HK$7.78=U.S.$1.00]

(e) Almost 60% of the families have children of varying age (from age 7 months to 15). Children are defined for the purpose of the survey to be age 15 or under.

(f) No attempt has been made to identify the contribution from grandparents in the families surveyed as this is deemed a topic for a separate exercise.

Questionnaires are designed and provided to these families through students and social contacts on a random basis. From those who returned the questionnaires, contacts were further made to solicit home-visits for interviews and photo taking. The overall response pattern for home-visits and photo taking is 40% and 35% respectively due to difference in attitudes towards personal privacy.

Concern 1 – Views

84% of the residents surveyed perceive that View is a main advantage or benefit of living in a high-rise tower (Figure 12).

This is a story of a young working couple in Hong Kong. Mr. And Mrs. Chiang moved into their newly acquired apartment two years ago. They had lived on the 6th floor of a 30 story residential development on Hong Kong Island, developed a craze for height in their new home. Because of that, the couple had no hesitation to invest on a seaward unit on the 30th floor of the newly designed waterfront complex that comprise 9 towers on a podium of retail complex and roof gardens and residents' club. The panoramic and picturesque view of Hong Kong Island over the Victoria Harbor is an eye-refresher for both of them day in day out.

On entering the Chiang's apartment, one is stunned by the superb view of Hong Kong Island, with the beautiful Victoria Peak as backdrop, and vibrant Victoria Harbor in the foreground. There is no doubt of what attracted Mr. and Mrs. Chiang to live here. The couples told the interviewer that the stunning view of Hong Kong, seen from every space in the apartment is an ultimate joy for them and their visitors. For the couple, relaxing in their computerized massage chair facing the Harbor view after dinner is an instant cure of stress and strain from daily work and was the main reason behind living on heights.

As in most other residential developments in Hong Kong, access to recreation facilities for residents and access to public transport network -subway and commuter buses (that offers connection to work within 30 minutes door-to-door travel time), and connection with neighboring retails and entertainment complexes is the secret to the wide-spread acceptance to high-density and high-rise living in Hong Kong. In this respect, Mr. and Mrs. Chiang are veterans in the sports game of bowling and goes to bowl in the shopping mall from time to time. Alternatively, they would visit the sound-surround cinema-plex or choose to socialize with their friends in a variety of eat-out places in the podium malls that are within walking distance.

Concern 2 – Quietness, fresh air and breezes

Apart from view enjoyed from the high-rise residences, the next perceived advantage of high-rise living is the enjoyment of quietness (47%), and fresh air (44%) (Figure 12).

Mr. Mok lives on his own unit on the 33rd Floor at Metro City. The 80 Sq. M. area apartment is a big sized home for two persons - Mr Mok and his father.

In the daytime, Mok works as an employed Architect in the City. Mok is a commuter and goes to work in air-conditioned public bus day in and day out. After work, he spends most of his leisure time in piano practicing and entering open competitions in piano performance.

He meets most of his friends at the local music schools found in the retail podium. After the music school, the company would eat and relax in one of many local cuisines in one of the three podium of Metro-City's. Mok's father is a retired person and spends most of his daytime either on the roof garden or with friends in the retail podium. So, for both father and son, most of their after-work and leisure time are spent at different locations of the retail podium close to where home is (Figure 13).

It is therefore interesting to note that the father and son spend most of their working and leisure activities within the community where they live. This is identical with Mr. & Mrs. Chiang, both of who work in the city but spend their leisure time in short distance from home.

When interviewed, Mok's reaction to high-rise living is a pleasurable experience of peace, quietness and enjoyment to fresh air and breezes due to extra stories over the rest of neighboring towers. For him, there was little concern over the distancing from work due to an effective public transport facility.

Mok's relationship with his neighbor is indeed an intimate one. In this case, his bedroom is designed with a large-sized window facing onto another residential tower of a near-by development. The window-to-window relationship is defined by a mere distance of 10 Meters or so apart, between the two towers, and invites doubts over privacy intrusion.

But interestingly, the response from Mok, who bought and resides in the apartment for three years, has little worry over the concern. For him, this is just another aspect of living in Hong Kong, and his reaction conforms to the Psychologist's depiction of a cultural adaptation in the social sharing of space.

Concern 3 – Effects on young children

98% of the families surveyed do not see any bad influence on the growing up of their children due to high-rise living. The few families who had bad experience or worries over undesirable impact on child growth caused by high-rise living are connected with their children's social interactions with other young ones. For these families, they would take more initiatives to compensate such disaffects or worries by taking their children to community centers or child centers for social contacts on a more regular basis.

Mr. and Mrs. Ho live in a massive residential complex on the southern shore of Hong Kong Island. Like most of his neighbors, Mr. Ho traveled daily to his office in the Central District by huge double-decker air-conditioned bus operated by the public bus company. Mrs. Ho stayed back at home to take care of their 7 years old son. The family lives in an apartment of about 65

Sq. M. on the 41 st Floor of one of 34 towers of the Southern Horizon Development, home to 5,000 families.

Families like Ho's are subject to investigating the impacts on the growing up of children in high-rise buildings in Hong Kong. Special questionnaire was devised with reference to Japanese researches and Japanese social experience**.** As a matter of fact, most parents in this group of families surveyed belong to the age group of thirties, meaning that majority of them were themselves actually brought up in high-rise residential buildings (During the Seventies, high-rise residential buildings ranged from 15 to 20 stories high, as compared with 30 to 40 stories in the Nineties). So the study was directed towards young parents who experienced growing up in high-rise living and aware of any impacts on their young ones.

The case of Mrs. Ho who gave up working in her office after giving birth is not uncommon although there are equal amount of mothers who remain working and rely on the support of either grandparents or more is the case today on employed amahs. (In Hong Kong, there are as many as half a million Filipino women employed legally as live-in domestic helpers.)

When asked about the impacts on her young one, Mrs. Ho gave a very positive answer against any noticeable undesirable impacts on concerns such as physical growth, social contact skills and maturity of her young son. This confirms the response pattern of other parents in this group of interviewees.

It is noted however, most mothers are satisfied with the provisions of recreational facilities available at their housing complex to counteract the worries over spatial need and social need to facilitate children's growing needs, the commonly found facilities are:

- Green space
- Trail and paths in landscaped surrounding
- Outdoor playground for young children
- Residential club facilities to include indoor games play rooms for children, indoor or outdoor swimming pool, reading and socializing space for children and mothers.

For Mrs. Ho, such requirements are well provided, as the South Horizon project is well known for its environmental and landscaping design. With three sides bound by the Aberdeen Sea, the towers enjoy good breezes, ventilation, attractive sea views, excessive planting and outdoor/indoor recreational facilities for residents.

Discussions

Discussion 1 – Future preference for house type: house, low-rise or high-rise?

This question was posed to the residents with an assumption that the residents had enjoyed a major improvement on their financial situation and desired to sell their existing homes so that they would acquire and live in a new residence of their choice.

Of those who replied, it is interesting to note that there is as high as 77% who still prefer high-rise living, followed by 16% who prefer shift over to houses, and 7% who prefer to live in low-rise buildings.

Tony Wilson, a government Chief Architect who has practiced in Hong Kong for over thirty years, used to explain the three contributing factors for a high-density and high-rise city – Changes (population), Compact (living), and Connectivity (the 3C Factor). From this, the author further develops his own interpretation of the rationale behind the above response**.** For the author, the success to high-rise and high-density living depends on three pre-requisites: Comfort, Convenience and Connectivity. Failure to meet any of the three would topple the acceptance for high-rise and high-density living. This is clearly echoed by the residents' response that they enjoy Comfort, Convenience, and Connectivity in high-rise living, and for the same reason, they would continue like living in high-rise towers.

Discussion 2 -- Comfort and Convenience

From the survey, it is clear that comfort and convenience are two related important factors for measuring the standard and quality of life. Here, comfort also meant security, safety and Comfort

Discussion 3 -- Connectivity and homework travel time

In his book, *A Scientist in the City* (1997), author James Trefil referred to an interesting discussion of "45-minutes" as a universal threshold to determine the acceptable maximum distance between home to work.

As expected, the "45-minutes" law has its stronghold in Hong Kong. In many of the surveyed cases, the travel time between home to work fall within 30 to 45 minutes.

As in the words of local Architect Rocco Yim, the city architecture of Hong Kong demonstrates a deep appreciation for connectivity of buildings in a cramped and at times dreadful urban set-up. In the case of Hong Kong, the acceptance of the connectivity concept is measured by local developers and designers' sensibility and readiness to connect buildings, and therefore, to connect movements and activities. In reality, Yim argues that the connections between buildings require not only an engineering ingenuity but, at the same time, a sense of aesthetics expressed in the art of making these connections.

Yim described this connective architecture as the 'Aesthetics of Connection', as seen in over 90 numbers of office buildings in the Central Business District, which are all connected in an efficient and elegant manner**.**

The same concept of connectivity is also found in other land-uses such as residential areas. For those expensive residences with breath-taking views built on mid-levels localities throughout different parts of Hong Kong, the rapid concentration of residences took no time to convince the government to plan a series of mile long escalator network to move people from home uphill to work downhill and vice versa. To day, the first of such escalator system was in use as a people-mover system. The so-called Central District escalator network or better known as the 'Soho' has an unexpected benefit. Within the first year of its operation, land-uses along the escalator network were transformed and re-vitalized by pubs and cuisines of all tastes, resulted in a re-generation of the area from a dilapidated state into a ultra-modern and stylish hang-out area for all ages.

In the urban areas, typical residential development conveniently adopts the podium concept by locating one to several towers on top of a podium which would accommodate the artificial ground on its roof and a multi-level car park within. Connection will be made to a neighboring public transportation node such as that of a subway station to offer connectivity and convenience to its residents (Figure 14). The development of the podium concept to combine, share and extend MILU function becomes an effective tool for public and private sector to combine and share community-based facilities. This practice is magic in the extension of rural area into satellite towns, as experience in Hong Kong (Figure 15). In the rural areas, almost all of the residential podium developments in a new town would connect by covered footbridges to help share the connection with public transport facilities such as trains or major transport terminal, as well as the sharing of retail and car park facilities in different podia (Figure 16).

The art of connectivity is visible in the new towns of Hong Kong. Shatin New Town was the first of these to incorporate connectivity in its town plan which mandatory required all developers to make connections with each other by means of overhead all-weather 24 hours access pedestrian bridges at the costs of developers (and ultimately the cost is transferred to the residents via the sale price of the residences). Today, connectivity is a daily acts for all kinds of land uses in urban and rural areas.

Discussion 4 - preferring a high-density, high-rise urban form

For Hong Kong, the occurrence of a high-density and high-rise urban form was probably due to extreme pressure from a shortage of land supply versus the demand for housing and other human activities. As pointed out, urban density in Hong Kong today achieved a world record. In retrospect, such ultra high urban density is caused by social and economic hardship experienced in the early days of the mid-sixties of the last millennium that sparked off exodus of refugees from Mainland China into Hong Kong. The Government then had no choice but to improvise it with mass housing schemes by means of economical and land resources within shortest possible time. In the forty years that followed, the mad-like rush was to meet the housing demand of a million populations increases every decade. Soon, it became apparent that low-cost public housing alone was insufficient to cope with the incessant demand for housing, and the private sector soon began constructing speculative housing consisted of residential towers with saleable flats targeted for mid-income families. The Government responded by a regulatory land sales policy that in no time became an inexpensive and effective tool to generate revenue for the Government.

If population-increase was the initial cause for the high-density urban form model, it is undeniable that economic consideration was a secondary but equally significant cause responsible for the high-density urban model. For decades that followed, land sales revenue account towards as big as 20% of the Government's annual budget, which facilitates Hong Kong to be one of the world's lowest taxation economy and a free capital market that draws in huge amount of international investment funds.

At the same time, economic achievements of Hong Kong in the area of textile, garments and toys industry have contributed towards the economic strengths of its people, which in turn led to an improvements in the standard of living and life quality.

The author summarizes the making of high-density and high-rise urban form in Hong Kong by four stages:

<u>Stage 1 1960s-1970s</u>

a. Substantiated growth in population.
b. Limited resources
c. Low quality and minimum standard

<u>Stage 2 1970s –1980s</u>

a. Regularized supply of land

b. Economic benefits brought by a high land price policy – the birth of a low taxation and free capital market

c. Emergence of Hong Kong as a financial capital market in the world
d. Emergence of Hong Kong as one of world's top 40 economies.

Stage 3 1980s – 1990s

a. Establishment of Environmental Protection Department
b. Country park and marine park ordinance enacted.
c. Operation of Mass Transit Railway and many highway systems

Stage 4 1990s onwards

a. Economic boom brought increase in GNP and salary levels.
b. Escalating of property price continued.
c. Changes in political governance and economy

Discussion 5 - Measure of Livability of High-density, high-rise Urban Form

The Paper presented several case studies to illustrate the development of a high-density and high-rise urban. It is worthwhile to note that because of the immense pressure from market demand, real estate developers and government planners adopted an empirical approach towards the collective search for a socially and economically viable solution. These case studies ended with experiments concluded during the Nineties that resulted in an ultimate model of an urban form that in turn bled a livable city.

The Hong Kong case study ended by referring to social, economic and health measure to justify the success of a high-density, high-rise urban form.

As it happens, majority of the world's Mega-cities are in Asia (Beijing, Shanghai, Bangkok, Jakarta, New Delhi, Dhaka, Tokyo) all of which exhibit the problem of overcrowding and overpopulation. Recent study[8] by the author shows that there is a growing demand for high-rise

[8] The co-author Lau and researchers in Hong Kong and Tokyo were awarded a grant from the Japan Foundation, Japanese government in 2000 to carry out a joint research study entitled '***Re-thinking our future cities, Hong Kong and Tokyo as model for Asian cities – empirical investigation of social, technological and ideological impacts of diverse cultures in making of cities into the 21st Century***'. The study resulted in the single out of socio-cultural preferences as the ultimate deciding factor in the choice of the lifestyle. After the end of the study, the author is engaged on an extended 2-year study to compare the lifestyle for young couples in the city of Tokyo and Hong Kong.

and multi-function developments in central Tokyo. For most of these Mega-cities, high-density living rather than the Urban Sprawl model becomes a daily practice instead of an skceptism.

For Hong Kong, high-density, high-rise is integrated with a high floor-to- area ratio (plot ratio) way of urban planning which continues to offer urban dwellers an exciting and comfortable lifestyle that prospers, and more significantly, influences the present and future prospects of the 600 or so expanding cities in China. Again to quote the words of Dutch researcher on Hong Kong, Stan Majoor, "the lessons from Hong Kong are valuable, because it demonstrates that high level qualities can be attained through 'labyrinth' design and attractive mixing of public, private and semi-public spaces."

<table>
<tr><td></td><td colspan="5">Maximum Domestic Plot Ratio</td></tr>
<tr><td>Residential Density</td><td colspan="2">R1***</td><td>R2</td><td>R3</td><td>R4</td></tr>
<tr><td rowspan="2">Metroplan Area</td><td>Existing Development Area</td><td>8/9/10*
(HK Island)

6/7.5**
(Kln & N.T.)

8
(Tsuen Wan, Kwai Chung, Tsing Yi)</td><td rowspan="2">5</td><td rowspan="2">3</td><td rowspan="2">-</td></tr>
<tr><td>New Development Area and Comprehensive Development Area</td><td>6.5</td></tr>
<tr><td>New Town (excluding Tsuen Wan)</td><td colspan="2">8.0</td><td>5.0</td><td>3.0</td><td>0.4</td></tr>
<tr><td>Rural Area</td><td colspan="2">3.6</td><td>2.1</td><td>-</td><td>-</td></tr>
<tr><td colspan="6">* Maximum domestic plot ratio of 8, 9, 10 depends on Site Class A, B, C respectively.

** The maximum domestic plot ratio is in accordance with those stipulated on OZPs and site class is not relevant.

*** R1 -- High density zone, with large capacity of public transport, such as railways, or public transport interchange, podium for commercial use.
R2 -- Medium density zone, with high capacity of public transport system but no commercial floor space.
R3 -- Low density zone, with very limited public transport, or area subject to constraint for urban design traffic, or environmental reasons.
R4 -- Detached or semi-detached houses up to 3 storyes high, including carpark.</td></tr>
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Table 1: Residential Densities in different regions of Hong Kong (Sources: Hong Kong Government, Planning Department, 2002)

Table 2: Land Use of Hong Kong (Sources complied from: The Quaternary Geology of Hong Kong, May 2000; Hong Kong Government, Census and Statistics Department, 2001)

Situation	**Covered by sea**	**land**	**Reclaimed land**
Percentage	60	38	2

Total area within HK region	= 2,904sq km
Land	= 1,076sq km
Sea	= 1,828sq km

Land use	**Urban or build up land**	**woodland**	**shrubland**	**grassland**	**agricultural**	**reservoirs**	**other**
Percentage	21.1	17.3	21.9	28.2	5.2	2.2	4.1

Table 3: Percentage of Different Types of Housing in Hong Kong in 2001 (Sources complied from: Hong Kong Government, Housing Authority and Housing Department, 2001; Hong Kong Government, Census and Statistics Department, 2001)

Types of Housing	**Public rental housing**	**Housing Authority subsidized sale flats**	**Hosing Society subsidized sale flats**	**Private permanent housing**	**Temporary housing**	**Non-domestic housing**
Percentage of population	31.9	16.1	0.8	49.0	1.1	1.2

Table 4: Percentage of Monthly Family Incomes in 2001

Class	**Poverty**	**Below average**	**Average**	**Above average**	**Total**
Monthly family income (in HK$)	<3,999	4,000 - 14,999	15,000 - 19,999	>20,000	-
Family Number	163,423	648,702	262,086	979,201	2,053,412
Percentage of total families	8.0	31.6	12.8	41.6	100.0

Figure 1: Population Growth in Hong Kong

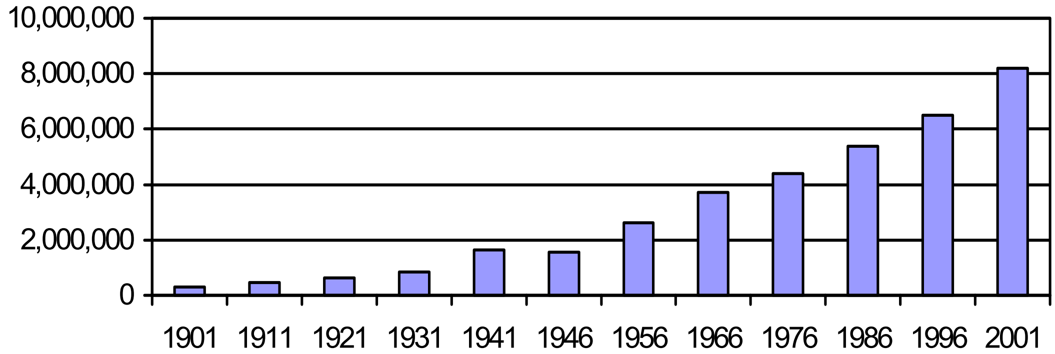


Figure 2: Extension of Space

Projection of space from the window is one of the most usual means of Hong Kong domestic householders to expand their living space, though usually the projection is composed by illegal structure.

Figure 3: A Chinese Restaurant

In Hong Kong, when most apartment homes have a relatively small area, many families prefer to entertain their guests or friends in commercial places as an extension of their homes.

Figure 4: Different Regions, Respective Land Area and Population Densities of Hong Kong (Source complied from: The Quaternary Geology of Hong Kong, Hong Kong Government, Census and Statistics Department, 2001)

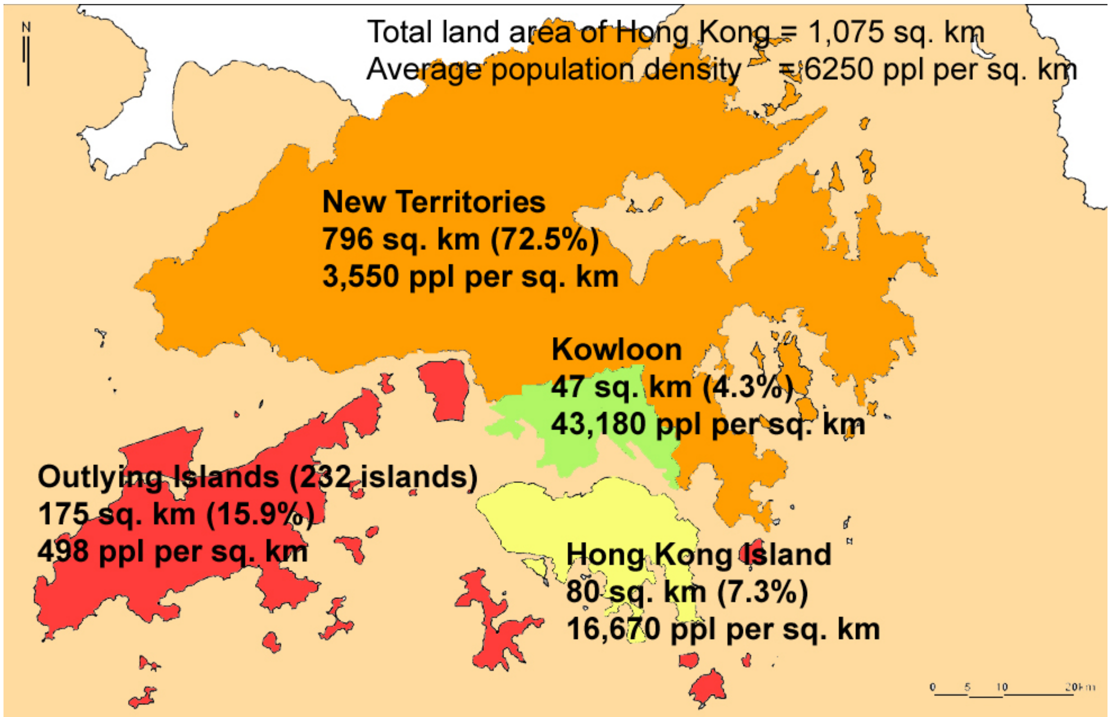


Figure 5:Prefereable analysis of preferable housing types.

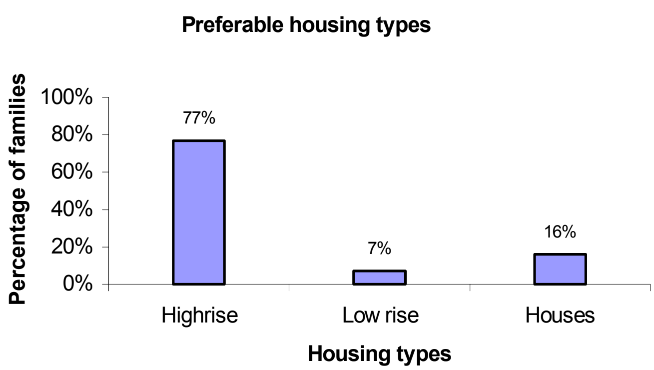


Figure 6: Central escalator system and pedestrian bridge

The escalator passes from Connaught Road Central, through Hang Seng Bank Headquarters & Central Market, goes uphill Cochrane Street, Hollywood Road, Shelley Street, Robinson Road & last at Conduit Road. Along the escalator, it is linked by varies commercial buildings and residential blockings. Also, in 1998, that region, together with the escalator, was developed to an international catering and entertainment area, which was named Soho, as describing the area **So**uth of **Ho**llywood Road. It is now becoming a famous tourist spot of Hong Kong.

Figure 7: Case Study 1 Mei Fu Shan Chuen

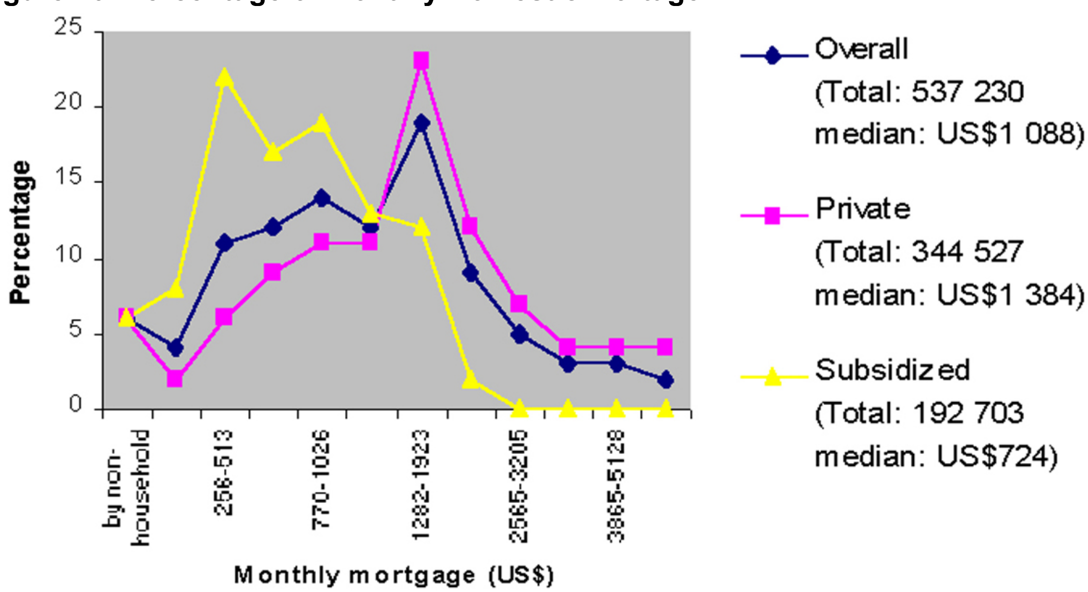
Mei Fu Shan Chuen started developed in 1969, and now has 117 towers of 15 stories tall apartment buildings crowding on four adjoining sites constituting a self-contained township for its 46,245 residents or 13,068 households living on a small but compacted urban site.

Figure 8: Shops on ground and residence on floors above

Figure 9: Case Study 2 Tseng Kwan O

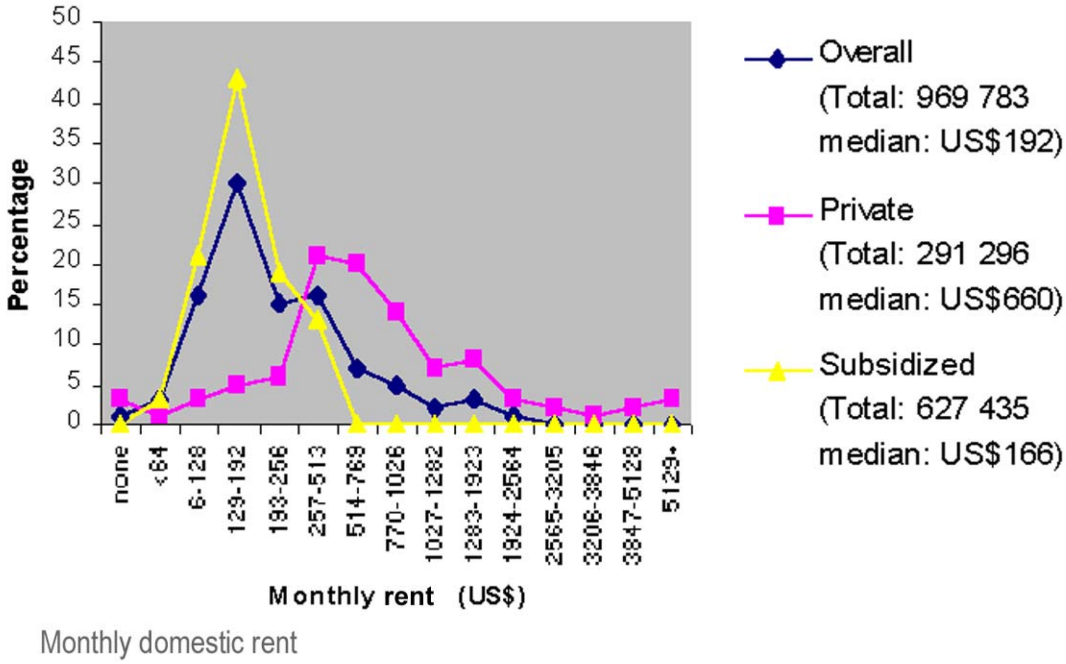
The podium is served as an artificial ground, on which sitting the recreational facilities and green spaces for the residents.

Figure 10: Percentage of Monthly Domestic Mortage



Monthly domestic mortgage

Figure 11: Percentage of Monthly Rent



(Sources complied from: Hong Kong Government, Census and Statistics Department, 2001)
US$ 1 = HK$ 7.8

Figure 12: Advantages of high-rise living

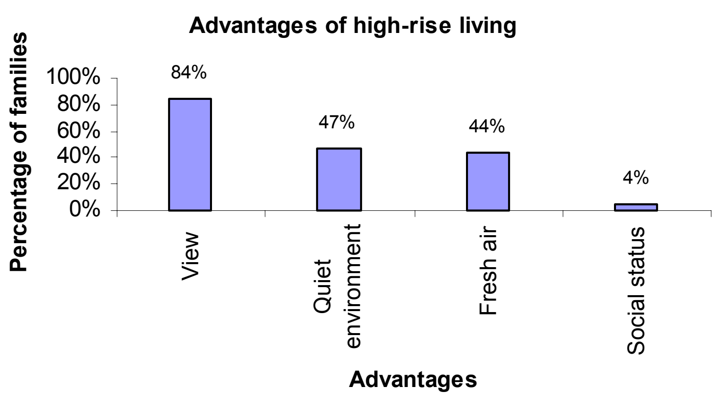


Figure 13: Green space on podium

Figure 14: Segregation of Traffic and Pedestrian Flow

This is a typical view of M.I.L.U. in Hong Kong: Office towers on top of a podium/ civic open space, pedestrian bridges linked with the podium and public transport interchange beneath the podium.

Figure 15: Conceptual diagram of MILU

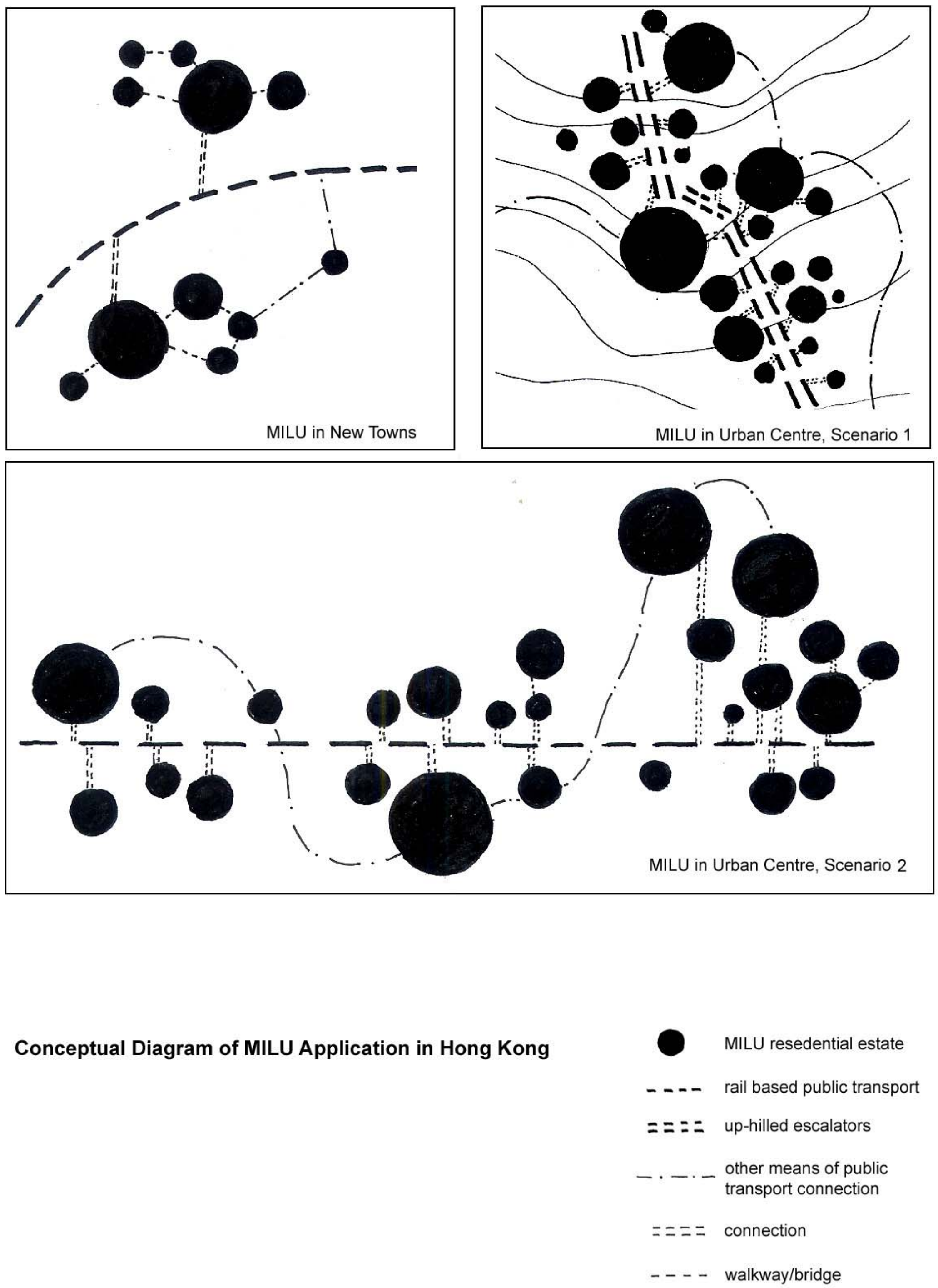
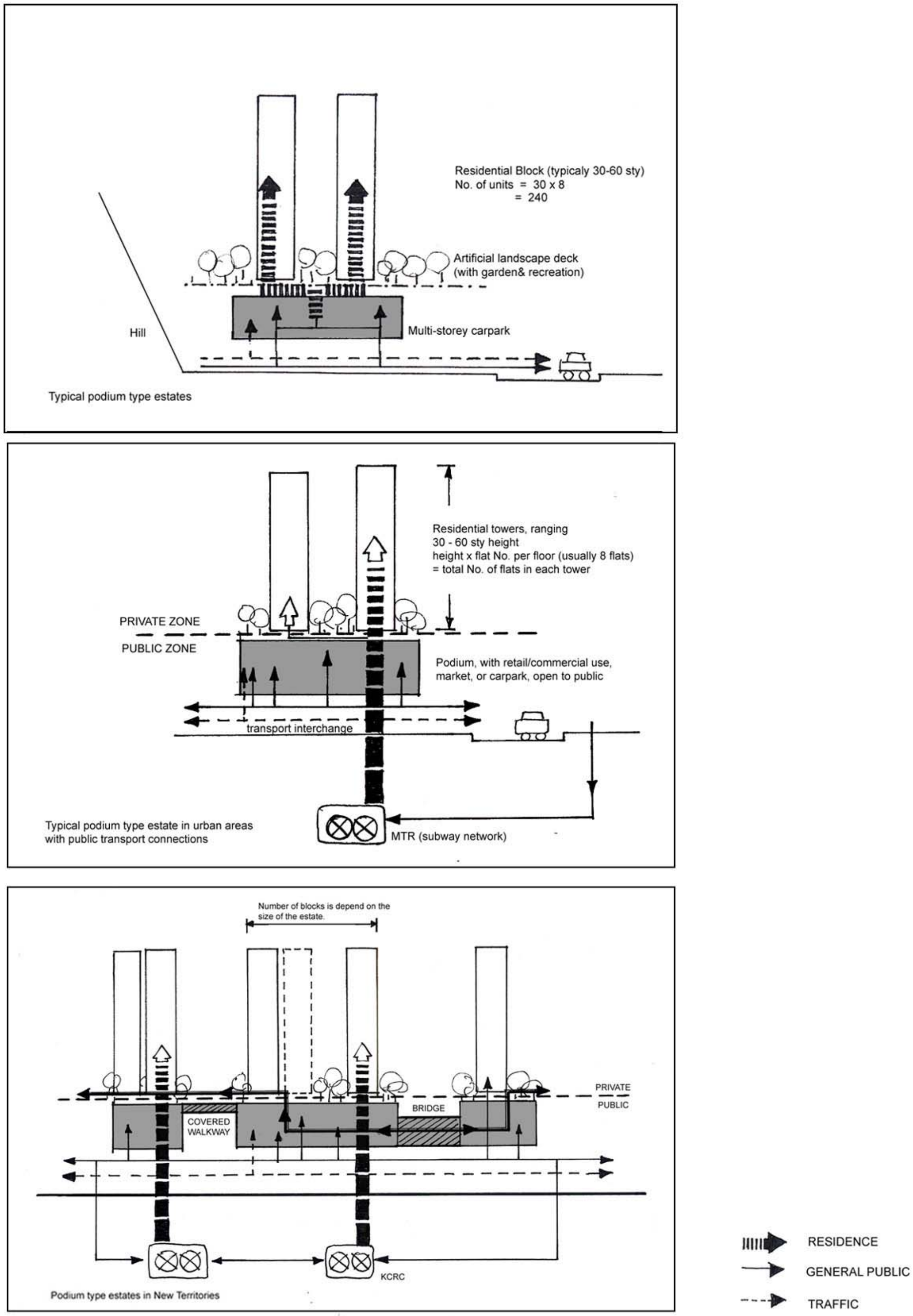


Figure 16: Schematic Section of Podium Development



Schematic Section of Podium Development in Hong Kong

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Arms, Wings, & Mechanical Things
analogue…assimilation…appropriation

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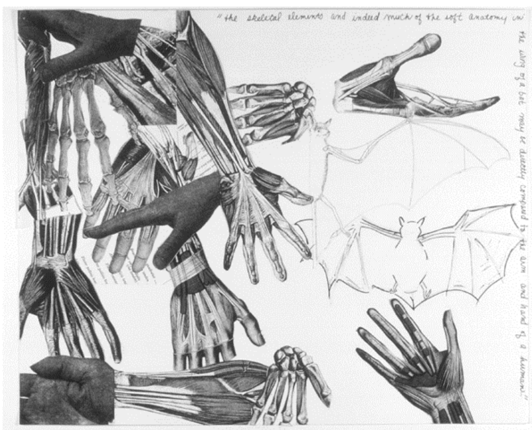
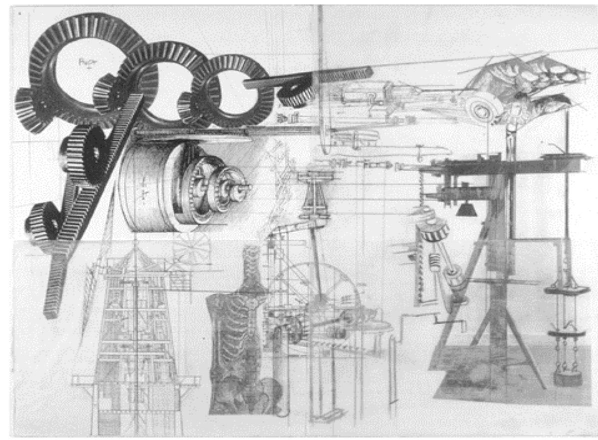




Abstract/ Introduction

Using analogy in the form of design assimilation, one is positioned to rely on his or her creative ability to associate and fabricate objects that engage materials into relationships that convey parallel meanings. These constructions can, in turn, establish formal orders that become the basis for an architectural grammar of details. Their meaning is gained through their ability to conform or transform to the context in which they are placed. These construction details can also be employed as a point of departure in the development of a design process. Through an analogical study of the joints in the body, the invention of a joint detail can form the basis of an architectural vocabulary that can lead to several forms of design development.

This studio is the third in the design sequence at our school. It acts as a bridge between the design principles of space and form stressed in your earlier studios, to issues of 'materiality,' 'structure,' 'modes of representation,' and the 'process of making.' Design exercises utilize analogical investigations to explore the expressive potential that material can achieve in structure and detail. The primary mode of representation will be models. Drawing will be used as a means of construing and constructing an idea. They will work hand and hand with the process of design. Imagination and invention will be emphasized in the process of interpretation and implementation of your ideas into highly crafted artifacts.

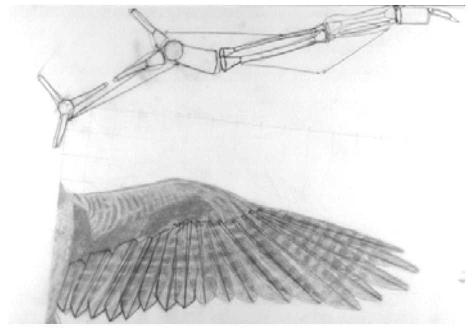
This design research will begin with the investigation of joints and connections and their dynamic forces inspired through our observation and analysis of the arm of the human body. Through comparative analysis we will study 'the wing' and make creative relationships with our studies of the arm. The goal of this phase of our study is to search for conditions that simulate the particular dynamic structural qualities of tensive and compressive forces found in the direct and indirect actions of the muscles and joints of these two body forms. From these findings, we will search/research existing mechanical devices that demonstrate similar differences and different similarities, to direct design and construction of assimilations of these conditions in the form of highly crafted small wooden models while simultaneously documenting their evolution through drawing. These exercises will eventually lead to studies that are specific creative structural and material propositions, such as, cantilevers, corbels, arches, trusses, hinges, and pivot joints. This form of study hopefully will provide "*pieces that can eventually mediate between building and user in crucial ways, serving both an intermediate scale that people can immediately relate to and a sensually crafted presence that invites tactile contact. They should also elicit empathetic responses with structurally explicit forms that are often shaped to suggest they have a life of their own.*"

These idiosyncratic pieces when subjected to natural growth patterns [component-element-unit, element-system network] become less striated or autonomous to become continuous systems that can form the basis for architectural projects focusing on such things as interactive walls, ceilings/roofs, spaces, as well as, multiple frame and panel assemblies.

In the Renzo Piano Building Workshop, the piece with its immediate responsibility to engender formal and tectonic negotiations also serves to generate systemic grammars that direct design and development:

More than anything, it is the piece that gives each building its particular identity: most of he buildings are as readily recognizable from the piece alone as by the whole. The pieces mediate between building and user in other crucial ways, providing both as intermediate scale people can immediately relate to and a sensually crafted presence that invites tactile contact, both especially pertinent qualities in buildings of large fluid spaces. The also elicit empathetic responses with structurally explicit forms that are often shaped to suggest they have a life of their own. But there are other reasons for picking on the piece as the focus of so much attention. It is the piece that is most susceptible to a sustained and objective refinement. Technical improvements to it are easily judged, and so are aesthetic ones. Many may contribute to this refinement, architects, engineers, and clients. And contributions can be made at all stages of development through sketching and drawing, hand crafting of prototypes and preparing shop drawings. With all this input, intellectual, visual and tactile, the piece is the one element that might approximate both the precise tailoring to purpose and the satisfying sense of being exactly right that is found in the products of natural evolution. Often too, the piece can and does continue to be refined long after the rest of the design has been settled. In an analogy from evolution, focussing on the piece could be seen as a neotenous strategy. (Neoteny is a way by which evolution speeds itself up by prolonging childhood, as in the case of humans, and so the learning period of each generation. Of course, in developing the piece the concern is not with a single object in isolation, but equally with what is created by the collective assembly of the pieces. Obviously then, connections are important, and so too is the whole that results when the pieces are assembled with all the other elements. Those who see the piece as a mere component that can be taken up and easily used in other designs, profoundly misunderstand its far more intrinsic role to a specific building, its scale and place ***(1)***

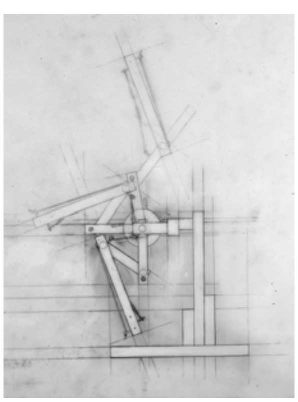
Forming Relationships Through Analogy



To begin the design process, the students are asked to research, collect images of the human arm, and make comparisons to collected images and descriptions of wings. After making an inventory their parts, they are to make speculations on the evolution or transformation between the two. Analyze the skeletal and muscular principles that direct its action and establish an individual focus on a particular aspect. They are to be conscious of the direct and indirect action of the muscles, tendons and joints and how they demonstrate the structural qualities of tensile and compressive forces.

Exercise One • the students are asked to make <u>two</u> collages, one focusing on the arm and another on the wing (on 11x 14 bond paper), relating their investigations by demonstrating findings through images, drawings, and words. Define relationships. Look for analogical connections. Associate and disassociate from the images you collect to find formal, as well as, literal correlation.
Exercise Two • after completing the collages on the arm and the wing, make a third collage (on 11x 14-bond paper) of mechanical things that have an affinity to your previous studies. Look for simple devices such as lamp arms, car jacks, umbrellas, drawing instruments, before extending your search into more complex machines. How did DA Vinci use the notion of prosthetics in the design of his mechanical inventions? How is a drawing compass a prosthetic device?

Drawing Constructions / Constructing Drawings



In this process of investigation and discovery, drawing acts as a means of construction, of ideas, of images, of analysis and of association. The drawings will be viewed as scaffolding; a temporary architecture used to help concretize an idea that leaves its trace in your final construction, allowing 2-D and 3-D to collude in the process of design.

observation/analysis, interpretation/translation, transformation/fabrication

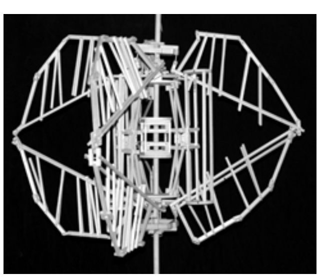
The next phase of this series of observations begins with a detailed enlargement of a particular wing scaled up at least double in scale. This means of magnification and rendering intensifies ones focus to prevent shifting attention to quickly assuring that observation will not be short-circuited into translation as mere imitation. It is more important to continue the seeing process by forcing hand/eye coordination to slow down permitting a closer look. It will allow the mind to wander generating creative associations to occur while rendering tonal gradations. This releases the daydream. It is in that zone that tangential co incidents collude to form new interpolations of hand/ mind and mind/ hand thinking.

The exercise will consist of three layers: Each layer will look at a different aspect of the wing: a realistic look at the nature of its parts, a geometric abstraction and a mechanical extrapolation. Each sheet conveys a distinct view of your specimen. All sheets are pencil on Mylar except the first sheet, which is on watercolor paper stock.

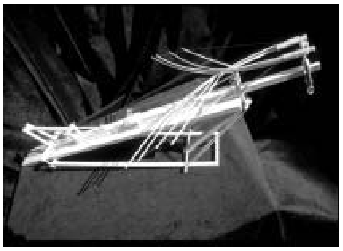
observation/analysis………………as is
We began looking very close so the eye could attain a tactile sense—inhabiting the detail. After reviewing the visual collages, each student clarified a particular perspective that would direct this next phase. Students now choose an appropriate image of their wing to further his/her research. Draw the wing at least twice the size of the photo to be placed in the middle of a 24x 32 piece of watercolor paper [hot press] leaving at least a 6" border on all sides for even closer studies. This first sheet is to be purely observation of the actual wing analyzing its parts through realistic close up rendering.
interpretation/translation………as ab
The next sheet is on Mylar and drawn in pencil to interpret the workings of the wing in a more geometric construction. This technique requires a translation of the parts into a geometric vocabulary viewed as an overlay upon the preliminary realistic drawing. This ***abstraction*** will allow you to see the workings as interpreted through geometry.
transformation/fabrication……as ob
This final sheet of Mylar will transform the visual information into a construction analog to direct the fabrication of a series of tectonic devices………..workable, buildable ***objects*** **two model**

SIMULATION vs. ANALOGY

simulacrum



From their studies, each student created a *mechanical simulacrum* that could demonstrate the dynamic actions from their wing analysis. Using the form language they derived from the geometrical abstraction (sheet #2) these constructions attempted to translate the actions of the wing in its *entirety* not as a series of disconnected joints. [resemblance is good]



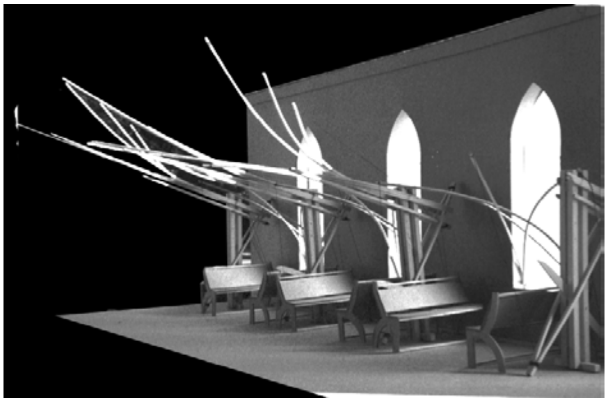
analogue
This model developed as a *mechanical analog* to a specific part or detail of their wing analysis. It gained its potency from the nature and fit of its parts. This model did not attempt to resemble but to demonstrate metenomically the action of a particular condition. The parts could be separated from their context or viewed as a series of parts disconnected form the whole. [resemblance is not good]

Definitions
sim·u·la·tion n
1.the reproduction of the essential features of something, for example, as an aid to study or training 2.the imitation or feigning of something 3.an artificial or imitation object 4.the construction of a mathematical model to reproduce the characteristics of a phenomenon, system, or process, often using a computer, in order to infer information or solve problems
sim·u·la·crum n
1.a representation or image of something 2.something that has a vague, tentative, or shadowy resemblance to something else
a·nal·o·gy n
1.a comparison between two things that are similar in some respects, often used to help explain something or make it easier to understand 2.a similarity in some respects
an·a·log or an·a·logue n
a chemical [construction] with a similar structure to another but differing slightly in composition. (3)

re-MAPPING the FINDINGS

The development of these models continued simultaneously to the evolution of the constructing drawings, each informing the other in an interactive dialogue. Each model obtained intrinsic value in relation to its function but also acted as an initiator to new refinements and innovations. They were well crafted, where each and every joint and connection acquired a distinct character. After this phase of work the students and I discussed the potential value of their discoveries and attempted to assign roles, relationships, and functions to their architectural constructions. We attempt to find what the systems do by looking at function as a response to the manufactured artifact rather than as the initiator of design. How can the meaning of their tectonic inventions be derived through a re-mapping of these constructions as applied to several architectural situations? Do they become roofs, walls, or both simultaneously? Can they adapt to the body from which they were derived...housing habits as prosthetic extensions? The building systems led this form of dialogue.

In several applications, the architectural projects turned to the body to generate function and application. Interactive wall and ceiling systems were designed as gallery display installations for exhibit and small pavilions, as well as, complete architectural interventions into dissimilar shells.

AN ARCHITECTURAL INTERVENTION

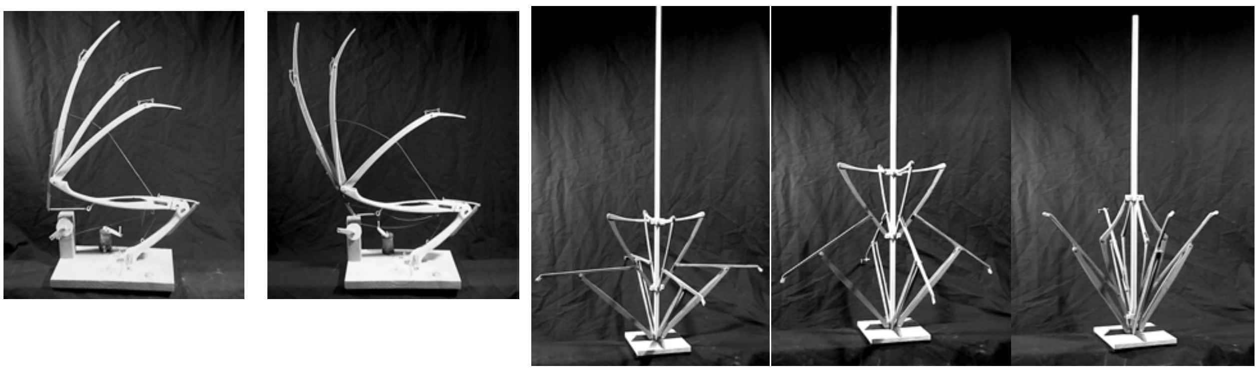
According to the American Heritage Dictionary, **to intervene** means*; 1) to come, appear, or lie between two things, 2) to come or occur between two periods or points of time, 3) to occur as an extraneous or unplanned circumstance, 4) a. - to come in or between so as to hinder or alter an action, b. - to interfere, usually through force or threat of force.... (4)*

The Unitarian Universalist Church in North Bethlehem asked us to design a temporary inner architecture that would give clarity to the nature of their new location in the remains of an old Presbyterian Church building. The interventions were to clearly speak to the present philosophy of the UU Church as a conceptual dichotomy coexisting within a predetermined context of another space and time (a brick miniature Gothic cathedral). Our design interventions should allow for a dialogue between the old (memory) and the new (imagination), the permanent (static) and the temporary (dynamic), the container and the contents, and the body and the building.

As an architect one is constantly confronted with this condition at all scales of the architectural project; from the relationship between two materials in a connection, to the formal relationship between two spaces in time. To intervene one must mediate or step in to form a negotiation between two, sometimes diametrically opposed, situations resulting in a resolution that is either *symbiotic:* mutually beneficial to each party or one that is *parasitic:* unilaterally beneficial to one party while being destructive and/or re-constructive to the other. Through rigorous and creative design thinking, the students were to propose interactive architectural frameworks that can make a place where science, spirit, and wonder commingle with function and experience. I originally prepared the early exercises to establish a tectonic vocabulary with this application in mind. Therefore, the students were to use their tectonic inventions previously developed as initiators for their design proposals. This process of translation and interpretation concluded as a series of architectural projects presented to the Church congregation. Many stimulating discussions ensued.

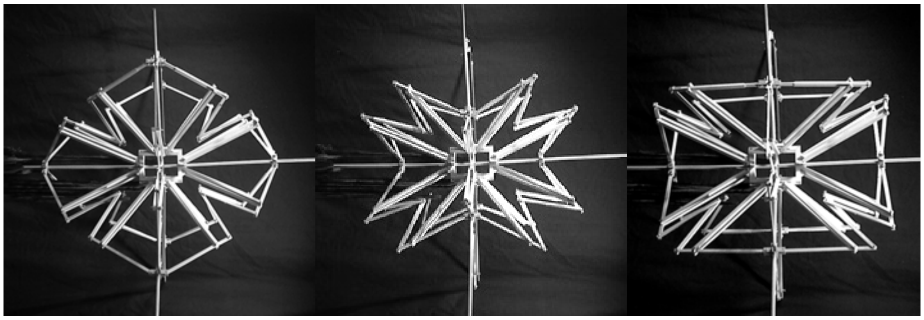
GROWTH ”the Form is in the Forming”

In all things natural, growth generates form. Without it, nothing would exist. Paul Klee in his pedagogical sketchbook refers to form as having a conjugational nature, allowing elements to transgress from active to medial to passive in the process of becoming. In other words, it is in the act of making or in the transformation of matter that meaning is allowed to be imbued into form…. “the Form is in the fORMING.”



In the first part of this study we focused on the nature of the part and the detail as the mode for analogy, starting the process with the body as a collection of parts that could be artificially separated from the whole. It is necessary to now to reconstruct the body and look it dynamically as an instrument of change or metamorphosis. Dynamic growth symmetries such as repetition and rotation can initiate causes of growth as a strategy to generate geometric moves on the field. These causes can further be clarified by studying the growth patterns of vegetables and minerals to understand and translate into guidelines for formal multiplication. These means of growth can be hierarchical in nature and rigid in their formative principals. Therefore, it would be important to look at the **rhizomatic forms** of growth (bulbs) and attempt to translate non-hierarchical growth patterns as form generators. This type of action can transform striated space (differentiated) into smooth fluid space through repetition, allowing the idiosyncratic to transform into collective meanings through multiples.

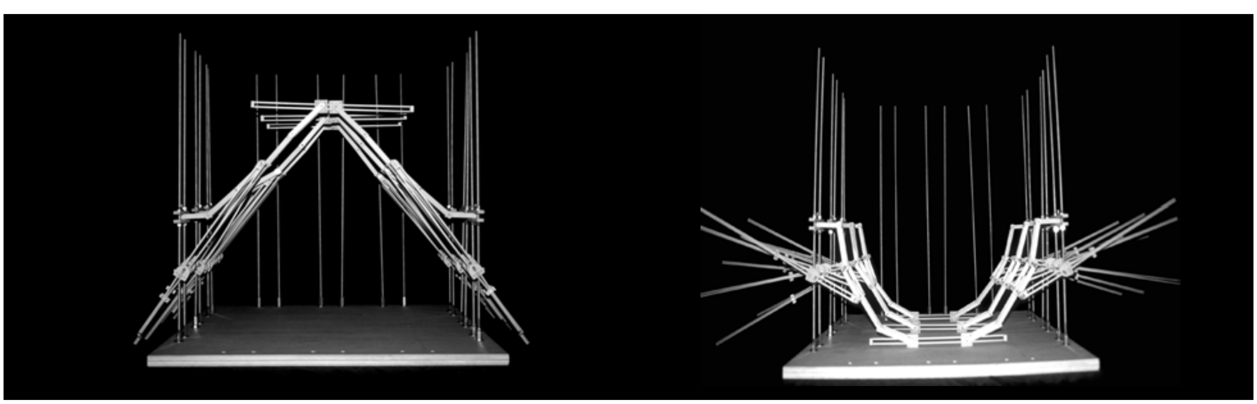
I will now conclude by presenting the results of a different form of inquiry. In this studio, I allowed the project to gain its meaning through its own conception and evolution. This is not just a description of one specific design studio though, but a proposition for a means of design thinking. To allow discovery to continue to regenerate upon itself, one must be placed in a more fluid form of thought/action experience. I have found that this regenerative process can be short-circuited when the design process becomes to goal oriented and deterministic early in the idea/design development. When the students’ design/research becomes more investigative in nature and reliant on analogical relationships they become more open to unstereotypical thinking and prepared for amazement.



This provides more opportunities for discovery and invention. Wonder becomes the motivation for the acquisition for knowledge and imagination provides the stimulus for thought. Meaning is derived from an implicit search for understanding formative principals rather than definitive conclusions.

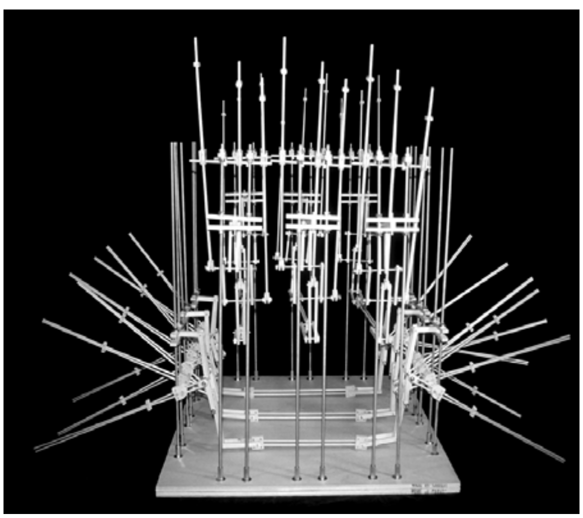
This is all predicated on a non-problem solving technique that allows palimpsests of analogical screens to generate new worlds of discovery thus opening up alternate views or perspectives. Through this type of investigative process new analogical screens are continually overlaid to project new interpretations of what one “sees” and interprets into their form transformation.

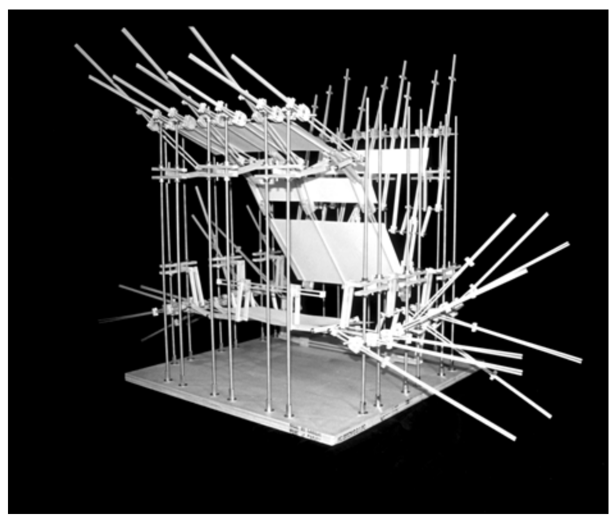
The challenge of keeping the discovery process fluid and open as you introduce more specific architectonic criteria is of great concern and difficulty. Ideally, the form gains its meaning and function through programmatic readings of it newly formed character. One might say that function and meaning, in this case, become a product of the imagination rather than the impetus for its action. As the implicit actions begin to collude with explicit targets, design gains a new dialectic form of intuitive actions and reactions followed by rational juxtapositions. These forms of thought/action fold into each other to present propositions *that* still allow the form to remain fluid with its newly found function and meaning. For once, function is allowed to be as fluid as form letting design research to remain open ended and implicit rather than deterministic and explicit in its nature. Granted the architectural practice must find explicit ways to address client needs but does this preclude the need for the art of invention as a means and directive for design inquiry? Can form be allowed to direct the search for meaning and resolution? Can function be the product of imaginative formal manipulations that foster the art of invention? These are not new questions and obviously the answer is yes, testified by the work and writings of great thinkers/inventors such as Leonardo DaVinci and Albert EInstein...”Imagination is more important than Knowledge”

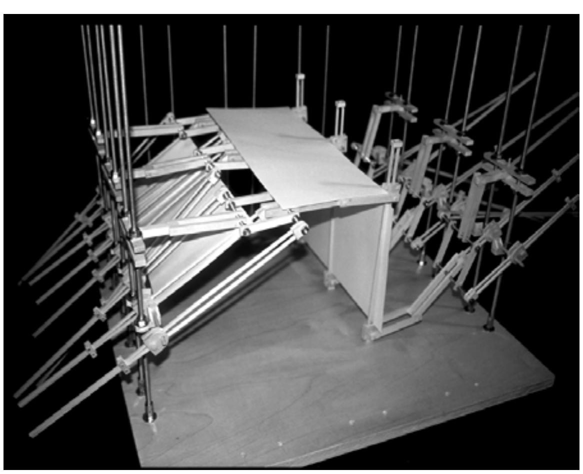


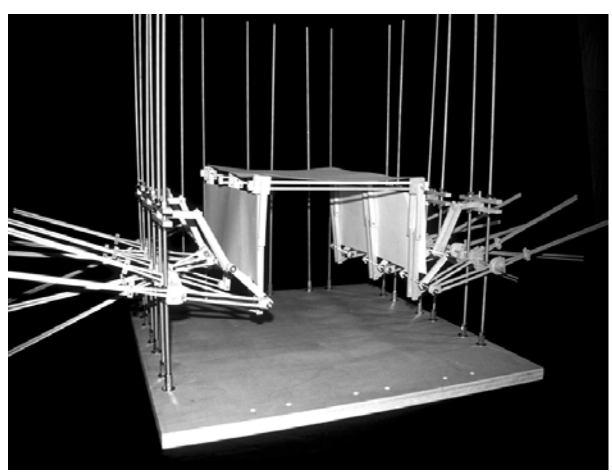
This next phase of the design studio began with our design research pointing in the direction of natural forms of growth and habitation. We began with three sketch problems focusing on vegetable growth, animal architecture and geometric patterns and constructions. After producing several pictorial collage studies, the students were now, to subject their idiosyncratic devices from part one to a rigorous series of growth exercises in drawing format to generate dynamic systems. [Specific symmetrical moves learned in earlier design studios were used as their guide in manipulating the growth of their constructions.

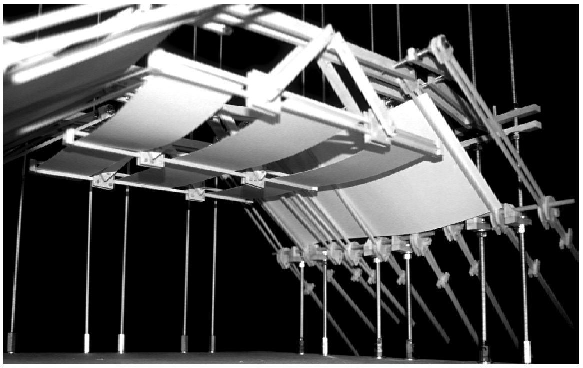
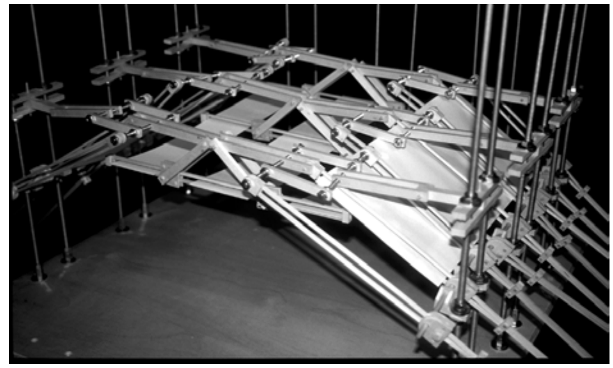
These studies were in direct response to the first three sketch problems. [The cumulative progressions of 1,5,50,and 500 were to be the range of growth projections]. The following series of images show several architectural propositions that demonstrate the studio's progressions from **simulation** through **analog** toward **appropriation**. This form of design exploration remains open and in constant motion. This is one of the most important aspects of my design research and the most mystifying aspect of our particular design methodology. It continues to reform-ulate upon itself..."the form is in the forming."









NOTES:

1. Time and Place, Technology and Nature in the Work of The Renzo Piano Building Workshop, 1996
2. Ibid
3. American Heritage Dictionary
4. Ibid
5. All images are of student projects. Photographs were taken and are the possession of the author.

Adaptive Systems Music:
Musical Structures from Algorithmic Process.

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Abstract

The generation of large scale structures at the level of musical form represents a major challenge for current approaches to generative music. This is especially true for approaches aimed at generating 'new music', which necessarily employ organisational principles other than those prescribed by traditional music theory. The Adaptive Systems Music project is an ongoing investigation of the use of biologically inspired self-regulating algorithms as compositional tools. This paper describes an autonomous algorithmic music system, designed to generate polyphonic audio. The main component is a self-regulating homeostatic network, based on a simulation of cybernetician Ross Ashby's electro-mechanical homeostat. Part of this network is used to generate 'homeostatic harmonies', the system dynamics producing an interesting musical structure. A rhythmic part is derived from the states of Cellular Automata, and a 'melody' picked out of the harmonies using a simple stochastic technique. The music generated has received high commendation in public appearances; listeners in a more rigorous evaluation conclusively supported its musicality. Their comments suggest that this may be attributable to the internal structures generated. It is suggested that exploration of possibilities in the sonification of simulated systems offers a fulcrum for sci-art collaboration and has potential to aid advancements in theory and practice in both domains.

1 Introduction

It has been suggested that one of the great achievements of AI is the construction of machines that can create music of high quality [1],[2]. However, the most successful approaches are dedicated to replication of music of an established style. By training on a corpus of work, or embedding stiff constraints derived from traditional music theory, convincing music in the style of Mozart [3] or traditional Jazz [4] has been produced. Attempts to compose 'new' music by computational methods *without* conventional constraints have been less successful.

Part of the problem of composing new music by computational methods is the inherent lack of cultural reference [5]. Human music is infused with cultural conventions and traditions that create expectation on the part of the listener and imbue the music with certain forms of 'deep' structure. Some of these traditions have been formalised, as music theory: the rules of harmony and form which govern the structures within classical, liturgic and other complex musical styles. It is these formal descriptions that have been embedded as constraints in systems such as Cope's EMI [3] and provide a certain 'musicalness' to the digital output. More primitive elements evade formalisation, being processed subconsciously. It is perhaps the absence of this level of cultural reference that differentiates Mozart's works from EMI's works-in-the-style-of-Mozart.

"*...when music is primitively compelling it forces its way into the conscious; when music is structured in a way that engages analytical and predictive processes, it invites itself into the conscious.*" Keane, [6] p.108

If these more primitive elements currently evade computational methods, and 'new music' necessarily does not subscribe to the constraints and structures of traditional music, are there any possibilities for generating audio that is sufficiently musical to engage the human mind?

One alternative to traditional methods that has been explored is the deployment of abstract models thought to embody some of the dynamics of the compositional process such as combinatorial systems, stochastic models, fractals and other iterative processes [7], [8], [9]. The potential for Artificial Life style models has also been recognised, and the use of cellular automata in the generation of musical structures has been explored eg [5]. Although these approaches have produced some interesting musical material, these consist largely of short fragments of monophonic note sequences. There are few examples of large-scale form, and nothing with any kind of 'rich internal structure'.

Another alternative is to pursue a longstanding preoccupation with the emulation of natural structures. Since the time of Pythagoras, we have been creating rationales for musical structures based upon "facts of nature" [6]. The potential for simulation of natural processes and structures has increased with advances in computational power, and it has been suggested that it may now be possible to develop algorithms of sufficient sophistication to create resonant relationships, for example between harmony and form [2], the possibilities of rich internal structure instilling a sense of the 'musical' in the absence of cultural conventions.

1.1 Rationale of Current Approach

The idea behind the Adaptive Systems Music (AdSyM) approach is to use biologically inspired self-regulating algorithms to generate music in the belief that their intrinsic properties can create musically meaningful relations. A 'bottom up' approach is adopted: the algorithms used can be characterised by the specification of local rules which induce global organisation. These are used to organise similarly low level musical elements of pitch and rhythm. Rather than subscribing to particular musical conventions to impose harmonic, rhythmic and high level form, the organisational mechanisms of certain algorithms are exploited to generate structures in these dimensions.

Rhythmic Cellular Automata Some consider rhythm to be the first and most fundamental element of music. It has been suggested that its repetitive nature has ties to diurnal and/or biological rhythms [10]. If the musical qualities of rhythm are linked to rhythmic patterns in the natural world, it seems possible that these qualities could be captured by a biologically inspired iterative algorithm. Cellular Automata (CA) are dynamic, discrete, deterministic systems, defined by sets of local conditional rules that determine the state of a certain cell according to the states of its neighbouring cells. Operating iteratively, the local rules induce global organisation. CA rules can be classified according to the nature of this organisation into homogeneous, cyclic, chaotic aperiodic or complex local patterned. The self-organisation and pattern propagation properties of certain CAs in particular have been used extensively in theoretical biology [11], computer sciences [12] and the generative arts [1] in investigations of morphology and pattern formation. Here it is hoped that the pattern propagation properties will transfer successfully to the auditory domain as a basis for rhythm.

Harmonic Homeostasis. In selecting a means of generating harmony, the role of traditional rules of harmony was considered, and a mechanism for creating meaningful relations between pitch values sought. Rather than considering 'meaningful' relations in terms of the natural harmonics of the 12 tone scale, a microtonal system is adopted, and harmonic relations determined according to the internal consistencies evoked by a homeostatic process. Homeostasis depends upon feedbacks, negative or positive, between a number of systems. For example during uterine contractions, oxytocin is produced which triggers an increase in frequency and strength of uterine contractions, producing more oxytocin etc. A homeostatic mechanism is adopted to generate harmonies, as the central feedback mechanism means that the value of each part is defined, not absolutely, but relative to all the other constituent parts, just as in a musical chord.

Higher Level Forms from System Dynamics Both these algorithms are essentially dynamic: the CA pattern, and homeostatic relations between parts develop in time (ie iteratively). By implementing the algorithm-audio mappings in real time, the algorithmic *process* is exploited to create rhythmic and harmonic structures. In biological systems, homeostatic processes are typically auto-regulating, for example critical triggering levels are adapted according to the state of the entire system. Biologically, this functions to maintain a range of conditions within which the body can operate most efficiently, even when there are radical changes in the external environment or internal system. More generally, the process achieves a robust stability within a multi-part system. Here, a self-regulating homeostatic network (see section 2.2) was developed with the intention that the system dynamics would produce long-term behaviour sufficiently complex to create musically interesting structures at the level of form. The successful generation of such structures may provide new possibilities for gaining insights into the underlying structural principles of traditional musical forms.

2 System Overview

The system presented here operates in real time, to generate polyphonic audio-output from separate algorithms operating within an iterative loop. Musically, the system produces three separate parts, voiced on different instruments. These can be conceived as a sustained four part harmony, a pitched rhythmic part, and a melodic part. The pitch values of all parts are derived from the outputs of a self-regulating homeostatic network, the timings of the rhythmic part are defined according to the states of a one-dimensional CA, and the note placements of the melodic part are determined using a simple stochastic method, all described below.
At each iteration, four pitch values are generated from part of the homeostat network, and the rhythmic and melodic parts voiced at these pitches according to the CA states and a set of randomly selected numbers respectively. The set of CA states and random values remain constant, and are repeated. Each part therefore repeats the same rhythmic loop with variation in pitch. When the homeostatic network stabilises (ie all outputs converge to a point or limit cycle) it is perturbed, pushing the system onto a new path, and creating new harmonies.

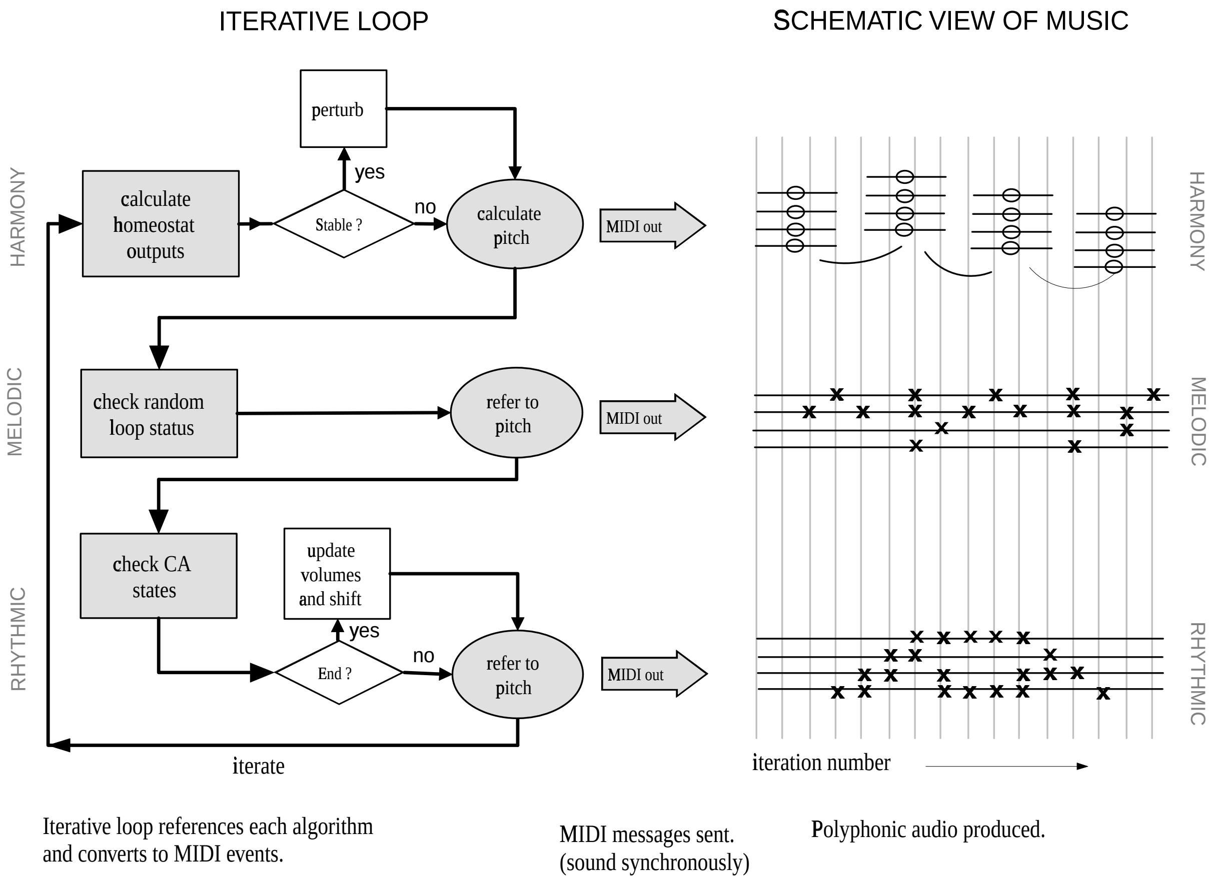

Figure 1: Schematic diagram of audio production from iterative loop.

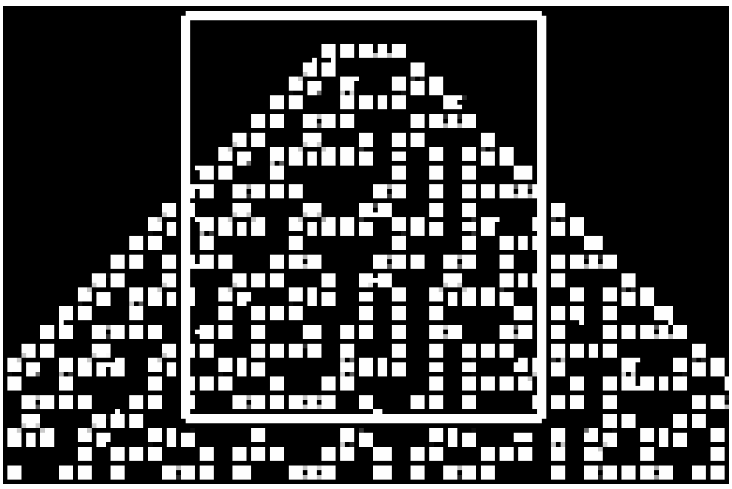

Figure 2: Graphical representation of 1D CA seeded centrally

2.1 Component Algorithms and Sonification

2.1.1 Generating Rhythm from Cellular Automata.

A rhythmic pattern is generated from the states of a one-dimensional (1D) binary CA. Although CAs can be generated using multidimensional states and spaces, a 1D CA was adopted as this is conceptually closest to our perception of rhythm. A 1D CA can be conceived as a row of cells that are updated synchronously at each iteration according to a conditional local rule set. A two dimensional representation can be created by simply presenting consecutive states as successive rows (see figure 2). The binary state of a particular cell at time t is determined by the states of the neighbouring cells at time $t-1$, graphically, those immediately above. The extent of the influential neighbourhood can vary and is here set to 1. The rule set for the CA used here is given below and is implemented on a fixed size grid.

neighbourhood states:	111	110	101	100	011	010	001	000
cell next state:	0	1	1	0	1	1	1	0

Sonification A rhythmic part played by four pitched voices is derived from the states of this 1D binary CA. The rule set above is used to generate the CA pattern in a 19×22 grid (demarcated area in figure 2). The states of the CA are interpreted very simply as a rhythmic score: on = play, off = rest. A fixed size grid is used and repeated (rather than running the algorithm in real time) in order to preserve the triangular shape arising from the central seeding. This creates a changing ratio of 'on:off', producing differences in the length of rests when voiced and therefore textural variation. Four consecutive rows of the CA are voiced simultaneously at the four pitches defined by the homeostat, but transposed exactly one octave down. Each voice reads along successive rows, the last cell in row n being followed by the first in row $n+1$. This produces a long rhythmic loop.

2.1.2 Simple loop melody

A third algorithm was developed to pick out a simple melody from the harmonies defined by the homeostat. The timings are determined by selecting four random numbers. These determine the period of the notes, so if 5,8,7 and 12 are selected, notes will be played on beats 1,6,8,9,11,13 etc. Each number is associated with one of the currently defined pitches, so notes are voiced at a *time* determined by the random value, at a *pitch* determined by the homeostat. In the example shown in figure 3, the notes G, A, B, and D are played every 5,8,7 and 12 beats respectively. This 'melody line' was included primarily as a means of highlighting the harmonic changes.

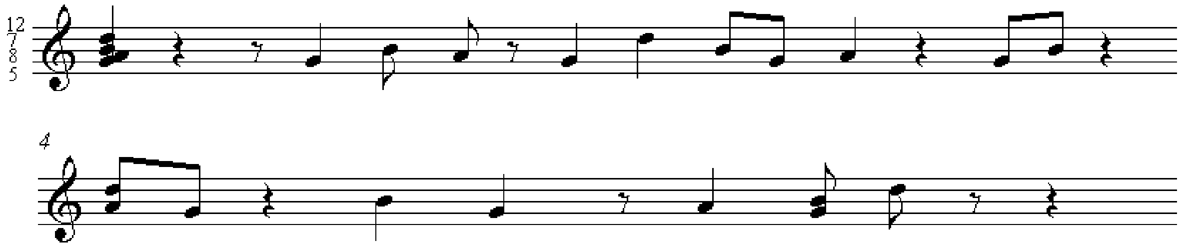

Figure 3: Transcription of example output from stochastic loop method

2.1.3 Generating Harmonies from a Homeostatic Process.

Dynamic harmonic relations are generated using an homeostatic process. An abstract formulation of the biological process of homeostasis was developed by Ross Ashby in a discussion of the origins of adaptation in living systems [13] and embodied in an electro-mechanical machine - 'the homeostat'. The current algorithm for producing harmony is developed from Ashby's original formulation.

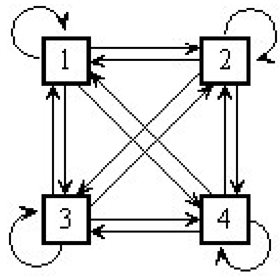

Figure 4: Diagram of connections for a fully connected 4 unit homeostat ($N = M = 4$).

A simple Homeostat A homeostat is conceived as a system comprising N units each connected to M other units, including a recurrent connection (see fig. 4). Operating in discrete time, the input to unit n at time t is the weighted output of all connected units (including its own recurrent connection) at time t (eq. 1). The output of each unit (at $t+1$) is proportional to the sum of these weighted inputs (*eq* 1). These weights are randomly initialised in the range -1:1, and are re-randomised whenever the output of the unit goes outside a prespecified critical deviation (set here to $+/-0.05$).

$$Output_{i(t+1)} = \sum_{j \epsilon c} Output_{j(t)} \times Weight_{ij(t)} \tag{1}$$

where c is the set of connected units, with i ϵ c.

The system approaches one of two qualitative states: *runaway* where the outputs constantly exceed the critical range in wild oscillation, or *stability* where outputs converge to a point or limit cycle. The probability of stability is a function of system size (number of units), connectivity (total number of inputs in the system) and level of damping. In the original (continuous-time) physical machine, damping was controlled by the viscosity of the liquid in which the outputs trailed. This is simulated (in the discrete-time algorithm) using a 'maximum change' variable, which defines the maximum difference in output values for any one unit over consecutive iterations. Once stability is achieved, the system is robust to minor perturbation (ie a change in any one output within the critical range). Forced deviations beyond this limit induce random weight changes in connected units and a renewed search for stability. *Suitable* weight values are defined, not absolutely, but relatively: the multiple feedback creating an internally consistent relationship between parts.

Sonification. The relationships between these parts provide the basis for harmony. The output values of a 4 unit homeostat are transformed into pitch values. Rather than restricting pitch to the 12 semi-tones of the scale of equal temperament, the outputs are converted into MIDI pitchbend values according to eq. 2. Pitchbend alters the pitch of a given note by a fraction of a semi-tone, here providing microtonal resolution down to $\frac{1}{32}^{th}$ of a semi-tone. Each unit

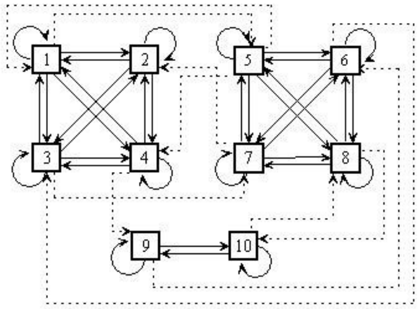

Figure 5: Schematic Diagram of Network showing Full interconnections and 10% interconnectivity

is assigned an initial central pitch value from which it deviates according to the value of its current output. Equation 2 with Pb Factor set to one therefore produces a pitchbend of $+/-$ one semi-tone when the output is at $+/-$ one critical deviation. At each iteration, the combined output values produce a chord, dynamic changes in output values creating harmonies. Harmonic structure is therefore defined by the homeostatic process.

$$\text{pitch bend}_{\,(i)} = (\text{output}_{\,(i)} \times \frac{\text{pb intervals}}{\text{critical deviation}} \times \text{Pb Factor}) + 64 \tag{2}$$

where
output$_i$ is the output of the i_{th} unit,
pb intervals is the number of intervals in a semi-tone (32),
Pb Factor is the user defined multiplying factor.
64 is added as the MIDI pitch bend command is centralised: values $0-63$ cause a decrease in pitch, values $65-127$ an increase.

2.2 Self-regulating homeostatic network

Whilst the process of homeostasis provides a new means of generating chords, a simple system stabilises quickly, producing uninteresting harmonies. In an attempt to create a system with more complex dynamics, as well as closer approximating the dynamics of biological homeostatic systems, a modular homeostatic network was developed in which the level of damping (maxchange) was self-regulated.

The network can be conceived as 2 four-unit homeostats and a two-unit homeostat (see fig. 5). Each are fully *intra*connected (bold lines) but the *inter*connections (dotted lines) can be varied randomly according to a user specified percentage connectivity. Rather than imposing a fixed damping constant, this value is derived from the outputs of one of the units according to equation 3[1].

$$\text{maxchange}_{(t+1)} = \frac{\text{output unit}_{i(t)} + \text{critical deviation}}{2} \tag{3}$$

where **maxchange** is the maximum amount by which the output of any one unit can vary over consecutive iterations.

[1]The equation was derived to invoke a relationship, in discrete time, analogous to the differential equation governing the damping effect of viscosity on a moving body.

The system exhibits more complex dynamics, whilst preserving the essential characteristic properties of homeostasis (see [14] for a fuller investigation). This network forms the main component of the present AdSyM system which integrates the CA rhythm, stochastic melody and homeostat harmony.

An initial and somewhat incidental exploration of dynamic and tempi changes is also implemented. Each time the CA is repeated, changes in the volumes of the rhythmic and melodic lines, and a transposition of the harmony part are made according to the values of other parts of the homeostatic network (see equations 4-6). The time interval between iterations (in ms) is decremented by 1 each time step, to a preset minimum. This is reset when the homeostat stabilises.

$$\text{Transposition Amount} = \text{output}_{unit_8} \text{ x } tc \tag{4}$$

$$\text{Melody Volume} = (\text{output}_{unit_9} + \text{critical deviation}) \text{ x } mvc \tag{5}$$

$$\text{Rhythm volume} = (\text{output}_{unit_{10}} + \text{critical deviation}) \text{ x } rvc \tag{6}$$

where
tc = 140. This value is not critical, but as the outputs will generally be in the range $(-0.05 : 0.05)$, this creates a transposition in the range $(-7 : 7)$ semi-tones.
mvc = **rvc** = 1270. The addition of a constant equal to the critical range, multiplied by this factor produces values within the MIDI velocity range of 0-127.

3 System Output

Audio examples of the 'music' produced by the system can be found at:
http://www.cogs.susx.ac.uk/users/alicee, and a transcription of an example extract is given in figure 6.

3.1 Public response

The AdSyM was very well received at two public appearances made at different stages of development. An early version, using just the simple four-unit homeostat to produce microtonal chords was used to open and close an electro-acoustic live set for the last night of a festival in Brighton (www.occulture.tv). Several audience members commented on its strong atmospheric effect.
The version as presented here, was played for several hours in a relaxed setting to members of *Blip* - a Brighton based Science/Art discussion forum (www.blip.alturl.com). The setting provided an ideal stage for the system, as listeners could experience the large scale structure of the system in terms of its progression through various states over an extended time. All those attending were 'very impressed' and commented that the system was 'exceptionally musical' compared to other, even knowledge based, generative systems. The Australian generative artist Paul Brown (www.paul-brown.com), the evenings' main speaker, showed similar enthusiasm.

3.2 Listener Survey

In a more rigourous setting, 20 volunteers, all unaware of the nature of the compositional process, listened to an example of the audio produced. Each then filled in a survey consisting of scaled questions and open questions (details can be found in [14]). There was significant agreement

Figure 6: Score of output from start of example run, with pitch bend factor set to 2. Top stave (marked I) shows the sustained four part harmonies generated by the homeostat, second stave (II) shows the 'melodic' part: the harmonies are played at times determined by the randomly selected numbers 3,14,2,15 with the quaver as unit time. Bottom four staves (III) show the rhythmic part derived from the CA (harmonies are inverted and played an octave down). Fractions at the top of each chord change qualify the traditional accidentals shown: for example the first chord should be read (in ascending order) D $\frac{3}{4}\flat$, E $\frac{13}{16}\flat$, G$\frac{13}{16}\sharp$, C $\frac{13}{16}\sharp$. These fractional accidentals apply across all parts.

that the audio produced was “interesting”, “musical” and “would be described as music”.

19/20 listeners agreed that the audio example they had listened to bore “qualities that they normally associated with music”. In elaboration of their choice, several mentioned the presence of many of the standard musical elements: *‘sense of melody ...driving sense of rhythm’*, *‘there were definite harmonies if unusual at times’*, *‘sense of harmonic and rhythmic structure and melodic progression’*. This reference to structure was made by several listeners: *‘structure and development on different timescales/resolutions’*, *‘certainly, if not composed by a person it must have been restricted in scale, structure etc.’*.

4 Evaluation

The exploitation of the process of self-regulating algorithms for the generation of novel music seems promising. In contrast to the ‘top-down’ imposition of rules of conventional harmonic systems, the multiple feedback mechanisms in the homeostat algorithm provides a bottom-up mechanism for producing harmonic relations in a micro-tonal system, which are interesting if unconventional. Similarly, the local rules of the 1D CA employed produce a higher level patterned structure that bears a strong sense of rhythm despite lack of consistent metre. Simultaneous presentation of several consecutive time steps voiced at different pitches produces some interesting accents and creates an almost melodic line. Even the selection of random numbers used to generate a ’melodic’ line is capable of producing some interesting phrases - although the success of this algorithm is much less consistent due to its stochastic basis.

Perhaps the most promising achievement of the current system, is the capability for the creation of higher-level structure derived from the dynamics of the self-regulating network. Examination of the outputs of the entire network over 2000 iterations (approximately 1 hour of listening time), shown in figure 7 suggests that the system passes through several qualitatively different states. These apparent phase changes are evident throughout the whole system and can be summarised:

iteration	0-250	250-700	700-950	950-1250	1250-1650	1650-2000
state	runaway	stable	stable	stable	runaway	stable
description	random	conv/osc	oscillate	converge	random	static

This progression through and return to qualitatively different states provides a rudimentary high-level structure. The stable-runaway-stable pattern is characteristic of the behaviour of a simple system at the level of individual response to perturbation. Here however, a similar pattern is also manifest at a higher level. This self-similarity across scale begins to increase the richness of the internal structure of the system.

5 Discussion

> *“...weird and surprising yet strangely familiar..”* listener 17

The main algorithms employed controlled musical events at the lowest level - simply defining positions in pitch-time space. However, the audio produced was conclusively agreed to be ‘musical’. It is not clear from this initial work *which* factors promote the perception of sounds in time as music. In this instance, it could be simply the familiarity of the timbre of the MIDI instruments with which the lines are voiced, or the somewhat arbitrary presence of dynamic and tempi changes. However, listener response suggests that any musical success may be attributable

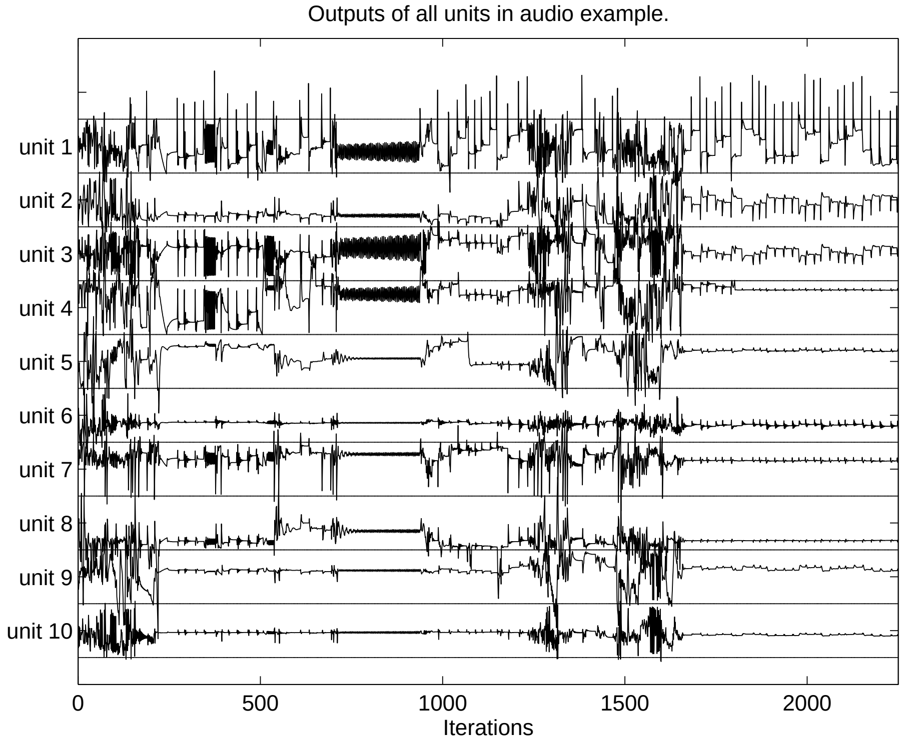

Figure 7: Graph of outputs of whole network over 2250 iterations

to the internal *structures* of the music which reflect the dynamics of the algorithmic processes.

The basic stable-runaway-stable (S-R-S) pattern characteristic of the simple homeostat when perturbed produces a basic balance of repetition and novelty. (A similar balance is present in the CA rhythm and stochastic melody, as the timings are repeated, but played at changing pitches). This balance arguably encourages cognitive engagement in the listener. Interestingly, this pattern of stability-perturbation-stability is evident in many musical and narrative forms: Larivaille proposed a 5 stage elementary scheme for narrative based on equilibrium-disturbance-reaction-consequence-equilibrium [15]. The same scheme is often applied to film narrative [16], and a very similar pattern is common in many traditional musics such as the exposition-development-recapitulation of Sonata form. In the homeostatic network used here, the S-R-S pattern of the individual unit is also manifest at a higher level in the overall cycle through stability, oscillation and runaway behaviour (see figure 7). This development of a pattern on multiple levels is seen in many complex musical forms. It seems possible that the higher-level dynamics of the network provide an internal structure that promotes 'musicalness', perhaps by engaging analytic processes in the listener, despite the absence of traditional musical conventions of form. This possibility must be methodically investigated. There are many other algorithms of this class within the adaptive and dynamical systems fields that have similar potential, opening up a new approach to algorithmic music. The reactive nature of the homeostat also offers potential for interactive systems as an alternative to genetic algorithm approaches to provide a degree of user control.

5.1 Potential for modeling

Consideration of the role of the internal dynamics of the system in producing musical material may also provide a basis for modeling musical processes. It has previously been suggested that CAs may share similar organisational principles to some elements of music [17]. The potential for modeling musical processes using CAs and other dynamic systems could provide an in-road into the development of an abstract theory of music, complementing current musicology of specific traditions.

5.2 Sonification in the arts and sciences

The system presented here is essentially a sonification of abstract simulations of natural adaptive processes. Scientific data has long been used as a basis for composition, and the use of auditory display in scientific tools is not new (eg the Geiger counter). However, increases in computational power provide new possibilities for artists and demanding consideration of new visualisation techniques across scientific disciplines.

Computer music pioneer Charles Dodge worked with natural functions such as fluctuations in the earth's magnetic field [18] and such approaches are becoming more popular with advances in enabling technologies [2]. This interest in objective structure has roots in the serialist techniques of the Second Viennese school (Boulez [19], Webern etc.). Such music still has a somewhat elite, but increasing, audience: this school of composition is perhaps more aptly considered as experimentation or research in contrast to the pure aesthetic aims of mainstream subjectivist composers. Within this framework, the exploration of simulated systems (rather than data from the natural world) offers great potential, both in terms of complexity and controllability.

Increasing computing power also creates ever-increasing amounts of data throughout the scientific community. The need to comprehend this abundance of data, together with advances in media technologies have promoted consideration of the use of auditory techniques in data visualisation. The rapidly developing field of computer modeling in particular - where data is often high-dimensional - presents particular difficulties for current graphical visualisation. Audio's natural integrative properties are increasingly being proven suitable for presenting high-dimensional data without creating information overload for users [20].
Further exploration of the sonification of simulated systems has the potential to contribute to scientific as well as artistic practices. The approach epitomises a current trend in sci-art collaboration, and demands interdisciplinary research effort with musicians and aesthetic experts assisting scientists in the development of intuitive mappings for sonification toward epistemological ends, and computer scientists contributing to artistic practitioners' understanding of the dynamics of aesthetic processes as well as the creation of new art forms.

6 Conclusions

Initial work employing self-regulating algorithms for the generation of new computer music is promising: the dynamics of such systems seem capable of producing structures of sufficient complexity to engage the human mind in the absence of traditional rules of form and harmony. The reactive nature of this class of algorithm also offers potential for developing more interactive systems. In addition to extending artistic practice, the sonification of simulations has potential scientific application as a data visualisation tool and would encourage a growing interest in science-art collaboration.

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Can a Genetic Algorithm Think Like a Composer?

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Abstract

There has now been a substantial body of work utilising Genetic Algorithms (GA) for the purpose of musical composition. A common point of discussion is how far GA's can simulate not just the musical output of human composers, but also the *process* of composing itself.

This paper begins by discussing the suitability of using a GA for composition, and goes on to describe a generative music system (by the author), that utilises a domain specific, knowledge rich GA. The system acts on a *supplied* 2-bar musical phrase (up to 4 parts), and evolves musical fragments towards a *supplied* target. The aim is to provide interim points on the evolutionary path, which represents a 'new' musical ideas audibly based on the supplied fragments.

The paper concludes that the system is able to model at least part of the creative *process* of composition, and is effective at producing musically successful results. (Audio download sources of its output are included to support this conclusion).

The system was used to generate music included in an interactive installation work, exhibited at Brighton Arts Festival 2002, and other applications under developed that use the algorithm are discussed.

1. Introduction and Aims

This paper is a musical and technical report on the development of an algorithmic composition system. The aim was to develop a system that would take in supplied musical fragments and generate *new* musically related fragments in response. An additional requirement was that processes used to achieve this should be modelled as closely as possible on common processes used by human composers.

2. Composition and Genetic Algorithms

Many mechanisms have been employed in the task of algorithmic composition, from the stochastic processes utilised in (possibly) the earliest example of computer generated composition: *The Illiac Suite* 1955 [1], to the more recent application of cellular automata by composers such as Miranda [2].

I decided to focus on the use of a GA model for two reasons: the increased use of GA's in generative artistic systems, and the resonance the simple GA model created with at least part of the processes used in my own (non-generative) compositional practice.

A Genetic Algorithm is a computer search technique, which derives its behaviour from some of the mechanisms found in biological evolution. This is done by the creation in a computer of a population of individuals represented by chromosomes, in a similar way to the chromosomes that we see in our own DNA. The individuals in the population undergo a process of simulated 'evolution', including mutation, crossover, and selection, in order to evolve a solution to the problem in hand.

GA's were originally developed as a 'blind' search tool. Indeed, a large part of their attraction has been the small amount of application specific knowledge required to achieve a goal. It was clear from the outset however, that in order to utilise evolutionary computing techniques to achieve the desired musical results a simple GA model would have to be specifically adapted to a more musical function.

This section deals with the relationship between the GA model and common human compositional processes. The paper then goes on to describe in more detail the devised algorithm and its applications.

2.1 What Aspects of Musical Creativity are Sympathetic to GA Simulation?

From a process perspective, musical material is often thought to be generated in one of two ways. Either ideas 'appear', or they are developed, which really leads us to the commonly used creative model of inspiration vs. perspiration. In trying to model musical creative activity we should at least consider these two approaches; how do they relate, and what aspects of either may be successfully modelled by an algorithmic system.

An often-used example of musical 'inspiration' is Mozart's ability to conceive entire works in an instant, and a well-known 'perspiration' example is Beethoven, who left evidence of his constant exploration and reworking in his many note books. This is succinctly summed up by Jacob [3]

> "In short, creativity comes in two flavours: genius and hard work."

Attempting to model inspiration, which in this context I mean 'instantaneous production', would be a daunting, and probably impossible task for many reasons, not least of which being the lack of current understanding behind such psychological mechanisms. It is possible that inspiration is a trick of cognition (in the sense that it may turn out to be identifiable as the result of a process of sub-conscious 'perspiration'), or even historical documentation. What maybe commonly seen as a difference between inspiration and perspiration may in fact be a distinction between composing and scoring. Rachmaninov was known to compose entire works in his head before committing them to paper, but because of the accounts we have which describe how he would take long walks in the country, humming and tapping his fingers in musical contemplation, it seems clear that there was still a process happening over time.

So, if creative inspiration is not clearly understood, and in addition the aim is to model compositional processes in some way, it appears sensible to concentrate on how musical ideas develop during identifiable and observable creative activities.

A commonly used compositional process may be described as taking an existing musical idea, and changing it in some way. Musicians in various styles and genres may follow the process differently, some through improvisation, others through pencil and paper, but what is most often practiced is taking an existing idea and *mutating* it in to provide a new idea. In fact mutation is closely related to notions of development, which lie at the heart of western musical concepts of form and structure. It may even be possible to see development as *directed* mutation.

In this model of [idea ⇒ mutation ⇒ new idea] we see three aspects to the creative act:

1. Creating/selecting the initial starting idea
2. The process of mutation itself
3. Assessment of the results of mutation.

With the core elements of GA's being mutation (including cross-over) and fitness assessment there appears to be a strong correlation with at least some aspects of the human *process* of generating musical material.

Do we escape the difficulties of ill understood inspiration mechanisms by using this model? There are still inspirational aspects at play when human composers follow variations on this process, primarily in the nature of applied mutations (the mutations are likely to be highly directed), and the act of selection or assessment. GA's are therefore no better or worse than any other algorithmic solution with regard to fundamental issues of artificial creativity, but because their process has some correlation with human compositional processes, they may make *integration* with human composers, in the form of creative support tools, more successful.

2.2 Composition as Exploring a Search Space

GA's were developed primarily as an *optimised* search tool. Even if there is a correlation between the mechanisms of a GA, and the (human) compositional process of [idea ⇒ mutation ⇒ new idea], can the aims of composers, who as a group are not usually happy to accept the most efficient solution over the most interesting, be met by mechanisms primarily devised for optimisation? If interesting pathways are to be found, any traversal through a search space should be guided in some way.

"...creativity is not a random walk in a space of interesting possibilities, but...directed".
Harold Cohen [4].

How then, is the search to be directed? The direction taken by a GA at any given time is determined primarily by the nature of the mutation and crossover operators, and the mechanisms for selection. Due to the clear importance placed on selection I will discuss this aspect in more detail later.

In a standard GA the mutation and crossover operators are random and take place on a simple bit array genotype. The bit array obviously has a task specific representation in some part of the system, but the actual manipulations take place on the *abstraction*, causing them to be more useful in a generic problem space but less useful in specifically *musical* manipulations. In order to make the GA more 'musical', two important changes are made to the algorithm with regards to mutation and crossover. Firstly, the phenotype was made less abstract, and more closely related to the problem space (the actual phenotype used in the system is discussed below), and secondly the mutation/crossover operators are designed with musical processes in mind. The algorithm makes *musical* mutations to *musical* genotypes.

2.3 The Fitness Function Problem

Much of the work previously undertaken in the area of using GA's for composition focuses on the problem of assessing fitness. Often determining what is 'good' about a particular genotype is equated to deciding what is 'good' music in a general sense.

There are two common approaches to assessing fitness:

1. Use a human critic to make the selection - an Interactive Genetic Algorithm (IGA). This requires an individual to use all the real world knowledge they possess to make decisions as to which population members should be promoted into the next generation.
2. Automatic Fitness Assessment. Which means encoding sufficient knowledge into the system to make fitness assessment automatic after each mutation and crossover process.

The problem with using an IGA, is the time taken to make assessments, described by Werner and Todd [5] as the "fitness bottleneck". This describes the difficulty in trying to assess many possible musical solutions due to the temporal nature of the medium. The benefit however, is that we are not required to develop a formal rules base. With Automatic Fitness Assessment we escape the fitness bottleneck, but face the daunting task of encoding the essence of the music we want to encourage.

In fact what we often see in examples of GA music are two distinct goals being suggested, if not explicitly articulated:

1. Creating 'original' music, where the aims are more closely aligned with the subjective process of conventional composition. When a composer sits down in front of a blank sheet of paper they don't normally feel the need to explicitly define 'what music is' before notes are placed on the page, even though what they write may in fact contribute to, or even extend, such a definition.

2. The 'objective' validation of a given rules-set, as well as other aspects of the algorithm, by providing compositional output as a test. In effect asking, 'how good are my rules'. Examples of this work include Wiggins [6], where the output is designed to be assessable 1st year undergraduate harmony exercises.

The primary difference of course is that the first goal is subjective and creative, whilst the second aims to be objective and may be seen as principally a musicological, or music-analytical task. I am not suggesting that the two goals are mutually exclusive, as most music students know, merely that much previous work tends to emphasise one or the other.

Baring in mind my previously stated creative goals, and my desire as a composer to map out a search space, I decided to supply the algorithm with a starting musical fragment to evolve from, and a target musical fragment to evolve towards. See fig. 1 below.

This has the effect of both directing the search and making fitness assessment significantly easier. The fitness function can then be described as the *similarity* of a specific genotype to the provided target music. The nature of the similarity test is described below.

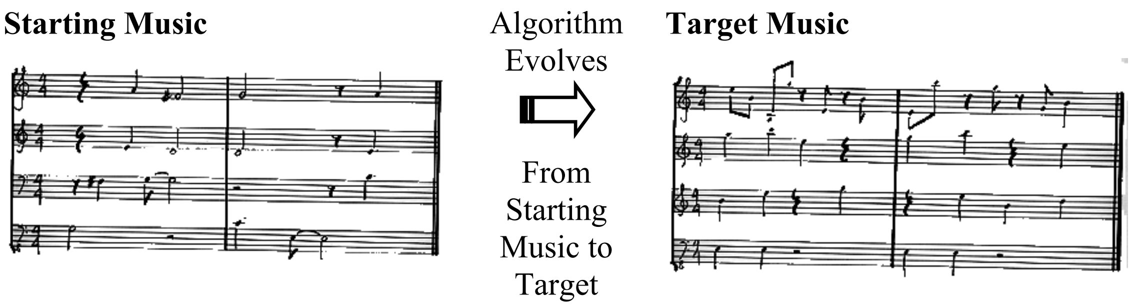


Fig.1 - Evolving from supplied starting musical section, to supplied target musical section.

3. The Algorithm

In this section I outline the steps of the developed algorithm, paying particular attention to describing the implementation details of the phenotype, fitness assessment and mutation operators.

3.1 Steps of The Algorithm

The individual steps of the algorithm are detailed below:

1. **Create initial population**

   A supplied 2-bar, 4-part MIDI[1] file provides the input to the algorithm. This is used to create a population of identical genotypes, which comprise the initial population.

2. **Select a population member (in turn) and perform mutation operators and crossover**

   As described above, rather than 'blind' bit flipping, the mutations have been modelled on processes used in musical composition, from simple addition and deletion of notes, to transpositions, inversions and reversals. Moreover, the application of any operators that require the selection of new pitches is based on a harmonic evaluation of the musical target.

3. **Assess the fitness of the mutated population member**

   Fitness is defined as how similar the genotype is to a supplied target. The details of this are discussed below.

4. **Accept into the population or discard**

   If the fitness value for the mutated population member is higher than the lowest fitness found in the population, it replaces the low fitness population member, and is stored as a

[1] Musical Instrument Digital Interface

musical point on the evolutionary path to the target, otherwise it is discarded.

5. **Repeat until the target is reached**

   All the musical sections produced, representing the evolutionary path, are then available as MIDI files. In effect these are an audible journey from the starting music to target music.

3.2 The Phenotype

Rather than represent musical attributes as a bit array, a simple musical object model was chosen. The Phenotype also contains meta-data attributes, which hold fitness values for each genotype, down to the granularity of a single note. A simplified object model for the phenotype is described below:

Section - The Section object is the outer object representing a fragment of music. It has attributes for target match fitness, and collection of notes (a table holding individual Note objects – its dimensions are 4 by 32, representing 4 parts to a resolution of a semi quaver).

Note – The note object represents the values for a single note, and has attributes for *velocity*, *pitch*, *duration*, and *target fitness* (0/1).

3.3 Fitness Assesment

Fitness of a genotype (musical section), is assessed on how *similar* it is the target.

It was stated above that each Note object in the genotype has metadata holding its fitness value. If this note has the same pitch as a note in the same position in the target musical section, it has a fitness value of 1, otherwise the value is 0.

Overall genotype fitness is defined as:

Musical Section fitness $= {}^{\mathbf{nSection}}/_{\mathbf{nTarget}}$ where,

nSection = number of Notes in Musical Section with a Fitness of 1
nTarget = number of Notes in the Target

It is therefore, simply the proportion of notes in the target section that have a matching pitch in the genotype.

3.4 The Mutation Operators

As discussed above, the system is required to evolve musical fragments towards a target, *and* generate musically interesting results on the way. These are potentially conflicting, multi-fitness functions, and the mechanism chosen for resolving this is to not assess musical interest directly, but include processes through the mutation operators that are more likely to provide a musically successful output.

The mutation operators used (presented in the order applied) include:

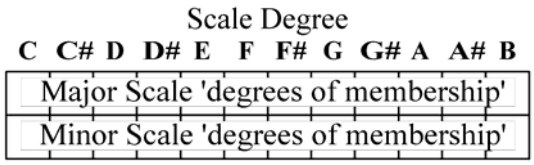
1) Add a note
2) Swap two adjacent notes
3) Transpose a note pitch by a random interval
4) Transpose a note pitch by an octave
5) Mutate the velocity (volume) of a note
6) Move a note to a different position
7) Reverse a group of notes within a randomly selected start and end point
8) Invert notes within a randomly selected start and end point. (Inversion around an axis of the starting pitch).
9) Mutate the Duration of a note
10) Delete a note

Each of the mutations listed is applied according to a user specified probability, and only to individual, or groups of notes, if the application of the mutation will not in any way alter notes that already have a targetFitness value of 1.

The fitness of each genotype is recalculated after *each* mutation. Therefore if a mutation has resulted in a note having a fitness of 1, it will not be mutated further. This optimisation of mutations enables the evolution process to be efficient enough to withstand interesting musical manipulations and still move towards the target.

3.5 Selecting New Pitches

When the system is started a harmonic analysis of the target musical section is made. A table is constructed (see fig. 2 below) in which each index location represents the target's 'degree of membership' of that scale type (Major and Minor), for that scale degree (C to B).



degree of membership = number of pitches present in scale/number of pitches

Fig. 2. This shows the table representing the 'degree of membership' of the target analysed. The table has values for only major and minor, but could be extended to include other scale type.

These analysis values, in conjunction with user-supplied weightings, are used to determine the *probability* as to which scale (eg. C# major) a new pitch should be drawn from when transposing a pitch within an octave, or creating a new note.

Once a scale is selected, the final pitch within that scale is chosen using a similar process. Now however, instead of the target music being analysed, the table is populated from an analysis of the other notes in the musical section being mutated. This is done for the *part* that the note is present in (so tending to create *melodies* from the same scale type), and the *chord* that this pitch will become part of (tending to create *harmonies* from the same scale type).

The degree to which this pitch selection process is applied maybe controlled by the user, giving the system a type of harmonic 'dial' that can be turned up to give tight constraints, or down to produce 'free' harmonies.

This rough estimation of harmonic analysis allows new pitches to be selected that are more likely to be present in the target music, but with enough fluidity that new harmonies will often occur. Of course, a more conventional harmonic analysis could be implemented, but this solution offers a more flexible harmonic model than methods associated with historical, *functional* (motion directed) harmony.

3.6 Crossover

After all mutations have taken place a random crossover is applied to the population, whereby note patterns are exchanged between population members.

3.7 The System is Interactive

Many aspects of the algorithm can be altered during running, including setting the probability of the application of each mutation operator (and changing parameters used to control them), use of crossover, and the degree to with harmonic analysis is applied.

4. Comments/Conclusions and Next Steps

The system certainly uses processes more closely related to those of a human composer than many other examples of GA composers. And it does, at least to me (and many of the installation visitors), appear to produce 'musical' output, which is clearly related to the supplied fragments.

It is interesting to note, although fairly predictable, that if all the harmonic restrictions described here are applied, the music produced is musical, but safe and lacking in novel ideas. As harmonic restrictions are released the music becomes more interesting, but with a greater tendency towards harmonic and melodic 'noise'.

It does of course, have serious limitations that restrict its usefulness. Chief among these is the small size (2-bar, 4-part) of the individual musical fragments that comprise its output. Although many of these are produced on each evolution run (usually ranging from 50-200), and it may be possible to argue that played in sequence they could represent a valid piece in the style of ‘process’ based musical forms associated with minimalism, I find simply playing the output stream in turn musically unsatisfying. It is the first stage in a 'bottom-up' compositional model, and was designed to work in conjunction with another system, see ‘Music Blox’ below.

Other possible next steps for further development include:

- Assessing fitness duration and velocity as well as pitch.
- Fitness evaluation could be extended beyond single yes/no note match, and could include an analysis of note patterns, which could be graded as closer or further away

from the target. For example if an inversion of a melodic pattern found in the target is created this may result in an increase in fitness for that genotype, exact matches of a melodic pattern would score higher etc.

- I have asserted that the mutation operators are based on some of the processes I find myself using when developing musical ideas, but an obvious next step would be to research the compositional processes of others, indeed to further explore existing research into general creative processes. Mutation operators could then be made both more suitable for an individual composer, and more complex as a combination of smaller elements.

5. Use of the Algorithm

5.1 nGen.1 – Interactive Public Art Installation

The system was used to produce the music for an interactive installation ‘nGen.1’ exhibited as part of Brighton Festival 2002, UK, and funded by South East Arts. The algorithm was run four times with the same starting and target MIDI files. Different parameters for the evolution were applied on each run, including the position of the harmonic 'dial'.

The resulting output MIDI files were taken at the 20%, 40%, 60% and 80% points (towards the target music). Therefore the four runs of the algorithm each produced four musical sections.

The sixteen MIDI files were octave transposed in order for them to be playable on the guitar, and each was recorded. Recording the output on a ‘real’ instrument enabled the perceived musicality of the fragments to be brought out, and provides additional musical dimensions.

For the installation, ultrasound sensors were placed on the wall and used to map out a virtual space for the sixteen recordings to be placed within, as shown in fig.3 below.

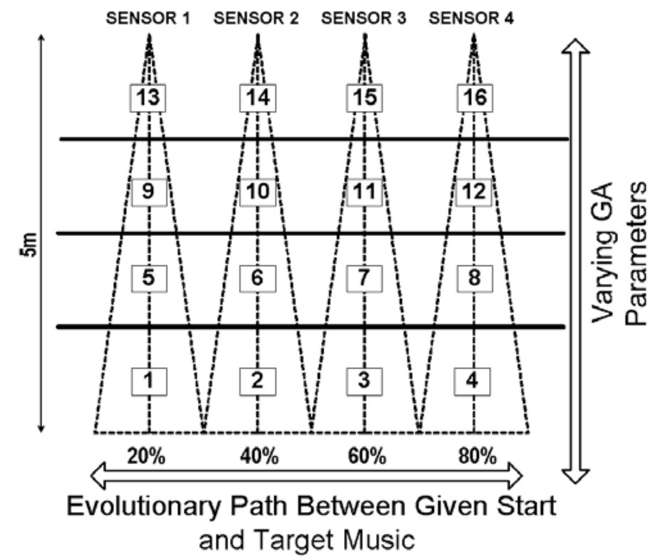


Fig. 3 – top view of area mapped out by ultrasound sensors

As people moved in front of the sensors the recording of an evolved musical section was heard.

The sounds in zones 2, 6, 10 and 14 are therefore all 40% evolved towards the target, meaning they have 40% of the pitches of the target. The evolution further away from the sensors uses stronger harmonic constraints, becoming more freeform towards the sensors. This creates a kind of musical logic to the ordering in the space, based on variation. Along the evolutionary path the variation is from starting to target music, towards the sensors it is variation of evolutionary parameters.

A simulation of walking along an evolutionary path (one with harmonic constraints, one without) may be downloaded at http://www.atgj.org/drew/, following the link to 'Musical Examples', 'Example of OriGen Output'.

5.2 Live GA Accompanist

A version of the algorithm has been implemented as a live accompanist.

In this application the performer produces MIDI messages, either directly from a MIDI instrument, or as a result of an audio to MIDI conversion package. The system then records 2 bars of the performers MIDI output, and uses the *last-but-one*, and *last* 2 bar sections recorded as the starting and target sections supplied to the algorithm. When the required fitness has been reached (default is 50%) the output is either played back directly, or sent to a scoring package for another live performer to read. The overall effect is therefore a recomposed delay of performer one played by the machine or performer two.

5.3 Music Blox

Music Blox is the primary reason for developing the algorithm, but is still in development at the time of writing.

The MusicBlox project uses blocks, similar in size and shape to children's wooden building blocks, which are combined together in a similar way to make physical structures. However, each block has the ability to play and compose music, so building a physical structure results in creating a piece of music.

Imagine you have a single block. You give it a small musical fragment (its 'home' music), put it on the table and start it off playing. The box then starts repeating its musical phrase, either sporadically or continuously. Make another box, this time with a different piece of 'home' music. Place it next to the first box and they start playing together, and in synch.

Now press a button on block 1 labelled 'send music'. This causes block 1 to send its music to block 2. Block 2 then performs a composition activity, based on its own 'home' music, *and* the music it has just been passed by block 1. The compositional aim for the block is to produce a *new* musical section that has relationships to both its home music and the music it has just been passed. Block 2 then starts playing its new music.

Now image a chain or group of several blocks in any 3D structure. If a block is passed some music it recomposes itself, then passes its new music on to *all* of its neighbours.

Block 1 sends its music to Block 2 – Block 2 re-composes itself.
Block 2 sends its new music to Block 3 – Block 3 re-composes itself.
Block 3 sends its new music to Block 4 – Block 4 re-composes itself. Etc….

All blocks have a 'send music' button, so the start of the chain does not have to be block 1.

By sending out music from a starting point all other blocks within a specified range recompose, and the collective music of the structure is transformed. The development of the overall piece of music will therefore be determined by how the blocks are built into structures, how these structures are changed over time, and how the user sends music around the structure. It is important to clarify that each block has its own 'home' music that it holds onto throughout. This enables any music composed by a block to remain related to the initial music supplied to it, despite the constant process of re-composition each block undertakes. In this way the composer of the home music for all blocks maintains a compositional thumbprint on the evolving musical structure.

In effect the listener/performer is able to shape the overall music by choosing to send musical fragments from boxes they like to *influence* other boxes. One part of the structure may have composed some ideas the user likes. A block from that group could then be placed in another part of the structure to see what effect it has.

Although the aim is to have physical blocks to build with, the present prototype exists only as a 3D graphical model.

6. Acknowledgements

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An Informal Shape Grammars for Interpolations of Traditional Bosnian *Hayat* Houses in a Contemporary Context

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Abstract

This paper explores the use of an informal shape grammar method for *Hayat* house form interpolations. Interpolations are new house forms, which carry stylistic characteristics of an existing design language but are inserted into a context, which responds to a contemporary life style. The study is based on a corpus of eight *Hayat* houses designed in the classic Ottoman style in the 18th and 19th century in Sarajevo. The *hayat* is a large shaded gallery open to the garden. It occupies the most important place in the composition of the plan. In this study, a form-driven design strategy is applied. The emphasis is given to new house form generation. The generation of a new house form within the grammar proceeds in four steps: (1) Primitive *hayat* house generation, (2) sub-house generation, (3) House variations, (4) House development. The shape rules used in the process of *hayat* house interpolations are mostly informal and explain in general terms how certain parts of the form are modified.

Shape Grammars: Analytical, Original

Shape grammars can be divided into two categories: analytical and original. Analytical grammars are developed to describe and analyse historical styles. Original grammars are concerned with the creation of new and original designs. The use of grammars for creative design has not been explored as deeply as the use of grammars for analytical studies. In this paper the use of grammars for creative design is explored. Formal Shape grammars deals with an algorithmic process of design. It is a method by which the application of principles to design can be explored. A shape grammar consists of rules of the form $A \rightarrow B$, where A and B are shapes made up of solids, planes, lines, or points.[1] A rule specifies that whenever a shape A is found in the design, it can be replaced with shape B. Shape grammars explain how forms are constructed.

Creativity in rule-based design lies in the creation of the rules. Rules can be modified and expanded at every stage of a design process allowing the designer to make explicit his/her design knowledge in a structured framework. The designer controls form-generation by explicitly defining the criteria for new designs that fit a given context.
This study utilises computational processes in type-based design to generate *hayat* house interpolations. It is based on a larger study titled “Design By Grammar: Algorithmic Design in an Architectural Context.[2] “ An informal shape grammar is used to generate primitive hayat houses that capture specific qualities of the *haya*t house type in Sarajevo. The grammar is not

merely analytical, aimed at describing a family of designs. And it is not original-grammar developed from scratch to generate entirely new designs. It spans between analytical and original grammars. The process can be summarised as follows. First a set of existing designs were used to infer the rules for primitive TYP. A *hayat* house generation. Three primitive *hayat* house types TYP. A1, A2, and A3 are generated. One of these, a house with a central *hayat* on both floors, TYP. A1 is selected for further elaboration. Than by applying the generative principles of shape grammar method sub-types of TYP. A1 are generated. And than variations of sub-TYP. A1 are created and developed with shape rules of addition and subtraction by introducing different constraints.

The rules are grouped based on their vocabulary and some based on the modification that they execute on the form. They are labelled in numeric order from 0 to 13. Some of the rules used in this study are self-explanatory and some are not. When necessary, detailed explanations of rules are given.

Hayat Houses

Eight *hayat* house designs from the 18th and 19th century found in Sarajevo, Bosnia and Herzegovina are the basis for this study. Two different sources of information (drawings and field trips) are used for the identification of the eight house designs.

Figure 1: Detached *Haya*t House

Figure 2: Semi-detached *Hayat* House

In its simplest geometric abstraction, the *hayat* house consists of two main elements, the rooms and the *hayat*. The *hayat* is a large shaded gallery open to the garden. It occupies the most important place in the composition of the plan. It is the backbone of the overall spatial configuration of the house. Its shape and size varies according to the geometry of the site and the size of the house. The house grew around this core, rooms and a hall, and the plan of the house continuously changed. The enlargement and development of the core pattern of the *hayat* house is based on the additive principle of design.3 The additional rooms around the *hayat* were build as the family expanded. Thus, it is difficult to determine an exact style of this domestic architecture. However the geometric simplicity of the basic schema of the *hayat* house allowed it to be modified according to each specific plot of land and also gave it great flexibility for future variations.

The *hayat* house is based on the dichotomy of semi-open and covered spaces. The main characteristics of the *hayat* house depend on its vertical and horizontal functional divisions. The horizontal plan of the house is divided into public and private spaces.

The vertical plan of the house is divided into two floors: the ground floor and the first floor. The ground floor whose geometry is often modified according to the demands of the site is semi- public and consists of a *hayat*, one or two rooms, a kitchen, and storage spaces. The first floor is used as private space and consists of a *hayat*, porch, and rooms.

Hayat houses named as TYP.A can be classified into three families of houses, depending the configuration and the elements of the ground floor. TYP.A1- a house with *hayat* at both levels, TYP.A2- a house with no *hayat* at ground floor level, and TYP.A3- a house without ground floor.

There are two types of urban *hayat* houses, detached and semi-detached. Although both have the same spatial configuration, the semi-detached *hayat* house integrates two (private and public) houses and two courtyards while the detached *hayat* house has only one courtyard. Figures 3, 4 and 5 illustrate the layout compositions of semidetached and detached *hayat* houses found in Sarajevo.

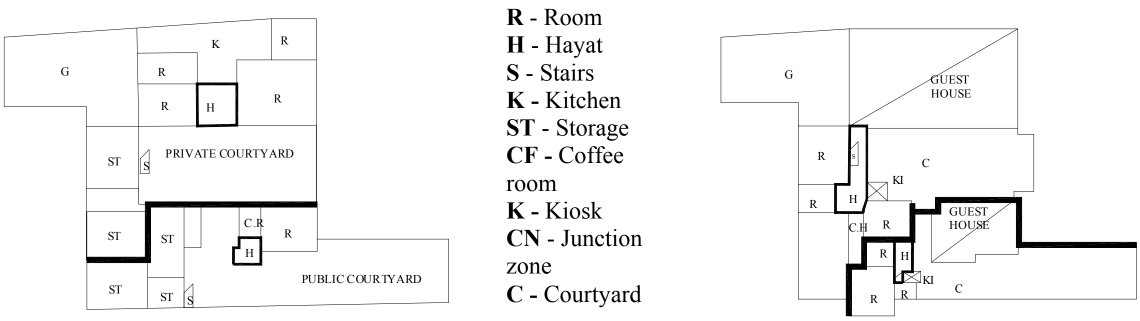

Figure 3: Svirzina, semi-detached house plan layout

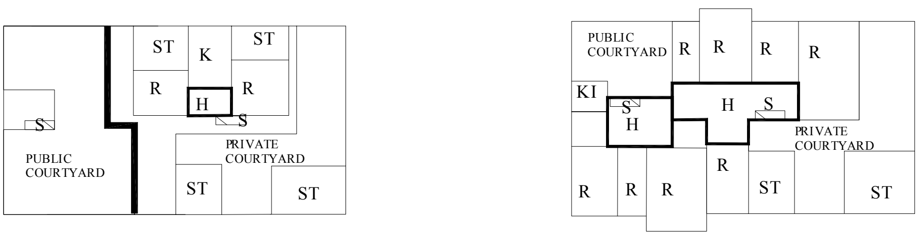

Figure 4: Dzenetica, semi-detached house plan layout

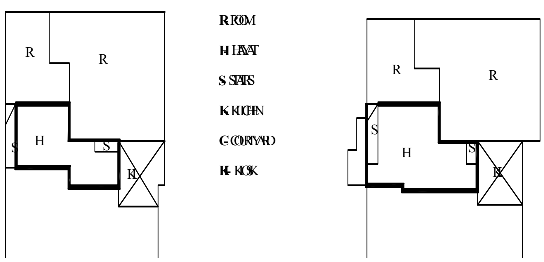

Figure 5: Saburina detached house plan layout

Design by Grammar

Novel interpretations of a *hayat* house are generated using a type-based design approach. Design types are constructed through the notion of generalisation. Here, design is considered as a process that begins with a primitive type and progresses to a specific design. Starting from a specific type to create a design emphasises certain relationships, over others that are treated secondary or are ignored as the design process progresses.

Four steps are used to generate interpolations of a *hayat* house:

1. Primitive *Hayat* house generations: generates three TYP. A1, A2, and A3 *hayat* houses.
2. Sub-house generation: generates sub-house types of TYP. A1.
3. House variations: generates variations of TYP. A1.1
4. House development: articulates TYP. A1.1 variations from 3.

1. Primitive *Hayat* House Generations

This first step illustrates the construction of primitive *hayat* houses. Here, the generic vocabulary, relationships between vocabulary elements and shape rule schemas that generate primitive *hayat* houses are extracted from the analysis of the *hayat* house precedents in the corpus. To define a shape grammar for primitive houses four phases are introduced:

Phase 1: definition of a vocabulary,
Phase 2: identification of the spatial relations between vocabulary elements,
Phase 3: creation of a family of spatial relations, and
Phase 4: definition of rules.

Phase 1
Phase 1 defines the vocabulary of the grammar as shown in figure 6. The vocabulary consists of five elements: the overall room space, shown as a U shape and labelled RS, can be used in both the ground and the first floor; the *hayat*, shown as a square and labelled GH for ground floor and FH for the first floor; the ground floor room space, shown as a rectangle and labelled GR; the wall, indicated by a line and labelled W, can be a part of a *hayat* or a ground floor room space; the stairs, shown as a rectangle with a diagonal line in it and labelled S.

To construct primitive houses, the ways that vocabulary elements can be combined with one another must be specified. The compositions of the vocabulary elements are given with spatial relations in phase 2.

Phase 2
Phase 2 defines spatial relations between vocabulary elements. Spatial relations are compositional ideas for making primitive *hayat* houses. Three of these spatial relations are illustrated in figure 7. They are defined in the following ways:

(1) Room / *hayat* compositions: a room (shown as a U shape) surrounds the *hayat*

(a square).
(2) Ground floor and stairs: defines placement of stairs on the ground floor. The stairs are in relation to the wall, labelled, W that can be a part of the *hayat* or ground floor room space.
(3) First floor *hayat* and stairs: describes the connection between the stairs and the first floor *hayat*.

In a spatial relation, the vocabulary elements can be arranged in many different ways. For the sake of simplicity, spatial relations with the same vocabulary elements, whether they are the same or different, are categorised in-groups and designated as family.

Phase 3
Phase 3 organises spatial relations with the same vocabulary elements but different configurations into family groups as shown in figure 8. Three family groups are illustrated. The first one illustrates two configurations: on the ground and the first floors, between the *hayat* and room space. The second family group illustrates the three different configurations between stairs and wall. Depending on the chosen house, the wall can be part of *hayat* or ground floor room space. For example, to generate TYP. A1 house rule 0.1 should be selected. This rule starts house generation with ground floor *hayat,* which has labelled wall on it. To generate TYP.A2 house rule 0.2 should be selected. This rule starts house generation with ground floor room space, which has labelled wall on it. In both, labelled walls indicate where the rules between stairs and wall can be applied.

The third family group illustrates five different configurations between the stairs and the first floor *hayat.* These spatial relations are the basis for the rules given in phase 4.

Phase 4
Phase 4 defines the initial shape and starting rules as shown in figure 9, and shape rules: group 1, 2, and 3 in terms of spatial relations as shown in figure 10. There are three different types of starting rules that define three different types of *hayat* houses extracted from the analysis: Rule 0.1 defines TYP.A1 (a house with a *hayat* at both the ground and first floor levels), rule 0.2, TYP.A2 (a house with no *hayat,* but only rooms, at the ground level), and rule 0.3, TYP.A3 (a house with no ground floor at all). In this study only TYP.A1 house derivation, and development is illustrated.

The shape rules specify the ways in which vocabulary elements of each type of house are put together. They are divided into three groups, corresponding to the three groups of spatial relations, as shown in figure 10:

Group 1 rules specify the location of the overall room space around the ground floor and first floor *hayat*.
Group 2 rules define placement of stairs on the ground floor.
Group 3 rules define the possible arrangements between the stairs and the first floor *hayat*.

Technically, group 3 rules operate on two different levels, the ground floor and the first floor. The left side of the rule determines the location of the stairs on the ground floor and the right side of the rule shows the location of the first floor *hayat* in relation to the stairs. The stairs belong to both levels and serve as a connecting element between the two. These rules determine the configuration of the first floor with respect to the ground floor.

1.1 The Application of the Rules to Designs

In this study only the derivation, and development of TYP.A1 (a house with a *hayat* at both the ground and first floor levels) is illustrated. The derivation of Typ.A1 house begins with a starting rule 0.1 shown in figure 9. The derivation is divided into two levels allowing the ground floor and first floor plans to be generated separately as shown in figure 11. The ground floor and the first floor plans are distinguished with different line thichnesses. Once the ground floor and the first floor plans are generated, then group 3 rules are used to connect the two floors with the location of the stairs. In order to articulate the space, a 3D representation of primitive TYP.A1 is shown as extruded plan.

2. Sub-House Generation

The second step for generating *hayat* houses consists of one stage. Here, by applying group 3 rules from step 1, five sub-types of TYP.A1 are generated as shown in figure 12. The location of the stairs plays an important role in sub-type generation.

3- House Variations

The third step for generating *hayat* houses consists of six stages. In each stage new shape rules are introduced. First, group 4 rules are used to transform sub-types of TYP.A1 for contemporary use. Than, group 5, 6, 7, 8 and 9 rules are used to generate variations of sub-types of TYP.A1. Each primitive house represents the beginning of a design alternative. Some groups have multiple rules while some have only one. The new shape rules are illustrated in figures 13 and 14.

The specifications for group 4 rules are as follows:

Group 4 rules modify sub-types of TYP.A1 for contemporary use, by transforming the first floor *hayat* into a central circulation hall as shown in figure 13. Group 4 rules operate on multiple levels. The left sides of the rules illustrate the composition of the *hayats* located on both the ground floor and the first floor. By applying these new rules of addition, the *hayats* on the first level are expanded, as illustrated on the right side of each rule. The elements of the different levels are distinguished by different line thicknesses. On the right side of the rules the new extension (*Ai*) is added to the front of the first floor *hayat,* so that it covers the ground floor *hayat,* and also extends beyond it a certain distance. This creates an overhang. Here the first floor *hayat* is transformed into a central hall by adding an extended *hayat,* which overlooks the garden and overhangs the ground floor *hayat.* Although the *haya*t loses its original function, the concept of it is carried on with extended *hayat* on the first floor. The extended *hayat* can be interpreted as private or semi-private space. The decision about its function and use depends on the designer's intention and on the program of the house.

Group 5, 6, 7, 8 and 9 rules generate elaborated variations of TYP.A1.

The specifications of these rules are as follows:

Group 5 rules mark emergent shapes as shown in figure 13. The left sides of the rules show the first floor as well as parts of the ground floor that are not covered by the first floor. The right sides of the rules show emergent shapes indicated by label *Xi.* These emergent shapes are used to expand the first floor layouts in further stages of the design.

Group 6 has only one rule. This rule partitions the U shaped room space at the first floor level into five sections, a1, a2, b1, b2, and c as shown in figure 13. These partitions are used to generate variations of TYP.A1 in further stages of the design.

Group 7 rules add new spaces, labelled *Xi,* above the ground floor to the first floor layouts, thus expanding the total floor area. Depending on the designer's conception, a variety of addition rules can be extracted.

Groups 8 and 9 each have only one rule.

The group 8 rule subtracts the section a1, a2, b1, b2 or c, from the first floor plan, thereby generating variations of TYP.A1. However, in the graphic representation of the rule in figure 14, only subtraction of section b1 is illustrated to depict how the rule operates.

The group 9 rule erases room partitions and units the rooms in to one space. Both Group 8 and 9 rules are generic and can be applied to both floors. In figure 14 the graphic representation depict how the rule operates.

2.1 The Application of the Rules to Designs

Figure 15 illustrates derivation of TYP.A1.1 house variations in seven stages. In each stage of constructing primitive houses a specified group of rules applies. Figure 16 illustrates a partial set of TYP. A1 houses generated through above given rules. These houses are abstract forms. They are articulated by introducing new relationships and modifying existing ones in the following section.

4. House Development

The fourth step in the generation of *hayat* house interpolations illustrates the development of TYP.A1.1 variations in four stages. Four new groups of shape rules, group 10, 11, 12, and 13 are introduced for house development. The new shape rules are illustrated in figure 17.

The specifications of these rules are as follows:

Group 10 rules illustrated in figure 17 generate different layouts of U shaped room spaces by partitioning them. These rules apply on both the ground and the first floor. The rules 10.1 and 10.2 generate partial set of partitions as illustrated in figure 18. Then rule 10.3 replaces the *hayat* with a new *hayat* (with attached partition walls) from the set. The type of chosen partition is identified by a number (tp*i*) in the set. Group 10 rules generate rough room layouts for both the ground floor and the first floor. These layouts are used as templates for further articulation of inner spaces.

Group 11 rules modify the first floor *hayat* in accordance with a given condition ($w1 = w2$) as shown in figure 17. The *w* indicates the width of the spaces (circulation areas) around the stairs. This constraint, which requires all widths to be equal, derives from functional concerns. Two issues are taken into consideration: creating functional circulation areas around the first floor stairs, and providing an access to the extended *hayat* from the first floor *hayat*. The default square shaped *hayats* are modified, depending on the location of stairs, and in accordance with the given constraint.

Group 12 rules modify the form of the house through another set of constraints as shown in figure 17. Here the emphasis is given to the configuration of the form and layout of the houses. The new rules, which modify the form and the layouts of the houses, are created on the bases of certain qualitative judgments, as explained below.

Rule 12.1 adjusts the uneven cantilevering portions of the first floor in relation to the ground floor as illustrated on the left side of the rule. The right side of the rule extends the ground floor with respect to the first floor under the constraint $l1 = l2$. The l here indicates the size of the cantilevering portion with respect to the ground floor. The rule generates even cantilevering portions on the first floor creating a visually balanced house form.

Rules 12.2 and 12.3 modify the corner of the room into an architecturally acceptable form. The left sides of the rules illustrate the adjacency relations between any two rooms on the first floor. On the right sides of the rules, the adjacency relations between the rooms are modified, creating clear-cut corners for each room.

Rule 12.4 elevates the extended *hayat* (Ai) from the first floor level. This rule is a generalised version of several rules. Only one vertex of the extended *hayat* (Ai) and the first floor *hayat* (FH) have assigned values (xi, yi, zi) to illustrate that the extended *hayat* is elevated from the first floor *hayat* under a given condition $z2>z1$. This rule is derived from the original *hayat* house designs in which some parts of the *hayat* have elevated floors. By applying this rule, the extended *hayat* is separated from the first floor, keeping its stylistic characteristics.

Group 13 rules transform the schematic house designs into architectural representations.
as shown in figure 17.

2.1 The Application of the Rules to Designs

In figures 19 and 20, TYP. A1.1 variations are articulated in four stages. In each stage of the development of the houses, a specified group of rules applies. Figure 21 illustrates a partial set of typologically related TYP. A1 *hayat* house interpolations.

Conclusion

In this study, a portfolio of typologically related *hayat* house interpolations is generated. An informal shape grammar is used to illustrate the practical applicability of a computational method for form generation.

This computational design method has two folds. First, it utilises the generation of standardised designs while respecting the existing stylistic characteristics in a given architectural context. Second, it provides an apparatus for continuing transformation of an existing type leading to a new type generation in language.

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Generative Architectural Design and Complexity Theory

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Abstract

During the past decades, complexity theory has evolved as a new discipline that provides a broad scientific perspective towards dynamic real-life phenomena, challenging the classical linear worldview as well as simple cause-and-effect-style Newtonian physics. For architects, the advent of this new science offers the challenge as well as the chance to reconsider common design approaches and to invent new strategies based on the new paradigms. The actual application of complexity theory to architectural design, however, results in a fundamental dilemma: How can a reflective, ultimately retrospective body of thought (complexity theory) be applied to prospective design challenges (architecture)? Being part of a current MArch thesis project, the proposed paper focuses on this general dilemma between architectural design and complexity theory and discusses actual as well as potential future generative architectural design approaches involving complexity theory. Generative design strategies commonly apply algorithmic methods and formalisms, which can conveniently produce and deal with high levels of complexity. Complexity describes general properties of a system and can be further dissected into several modes: epistemic, ontological and functional complexity. This taxonomy offers insights into generative design applications, which have mostly focused on a limited set of complexity modes. Besides complexity generated by sheer numbers, aspects like functional or hierarchical complexity offer further perspectives on generative systems, processes and output. Considering these aspects of complexity theory, future challenges to generative architectural design can be predicted.

1. Introduction

During the past fifty years, a major extension to classic natural sciences has changed many views on natural phenomena in general, summarized in the discipline called *complexity theory*. While these changes have affected mathematics, physics and biology for decades, the underlying thoughts are only beginning to be realized in other areas including history, economy or architecture. Complexity theory focuses on complex relationships of elements, which are not random but subject to mechanisms that generate order on various levels of organisation. Traditional science emphasizes stability, order, uniformity and equilibrium and focuses on closed systems and linear relationships. In contrast to that, complexity theory brings attention to disorder, instability, diversity, disequilibrium and unstable equilibria, and nonlinear relationships, which describe temporality and causality found in real-life phenomena more accurately than traditional scientific methods.

Venturi [22] proposed a first theory about complexity and contradiction in architecture in 1966. Then, complexity theory was still in its infancy, but the central concerns of Venturi's thoughts were the same as ours today: the search for a design approach that could work in real-life situations instead of isolated and idealized scenarios. Architecture has traditionally drawn on rigid forms of order that tended to be indifferent to environmental influences. Venturi's search was motivated primarily by the desire to find alternatives to modernism's emphasis on the linear and the grid-like with its strong tendency to ignore conflicts and difficulties arising out of complex situations. His search, coupled with an interest in scientific complexity theory, has been taken up again during the past decade. A number of architectural theorists have written about complexity in architecture, among them Jencks [12], Eisenman [7] and Lynn [15], but attempts to use complexity theory in architecture have rarely ventured beyond rather diagrammatic and iconic applications. After the novelty of the subject has worn off, the main question still remains unanswered: How can architecture be related to complexity theory? When looking at the characteristics of generative architectural design and complexity theory more closely, the generative approach to architectural design sticks out as a promising strategy.

2. Generative Architectural Design

Generative design is still a relatively new approach to architecture. Relevant terminology is yet based on rather vague notions, and encompasses a broad range of loosely related methodologies. In general, generative design can be described as a design strategy that differs from other design approaches insofar that during the design process the designer does not interact with materials and products in a direct way, but via a generative system of some sort [8]. In this paper, generative system refers to digital, computer-aided generative systems that are most typically but not necessarily developed by architectural designers themselves. Generative architectural design is a specific approach to design problems in the architectural field, and it reflects characteristic problems in design in general.

Design problems in architecture are unique, open-ended and ill-structured [19]. Therefore, solving design problems always requires problem-specific and to some extent experimental methodology. The uniqueness of architectural problems does not allow architects to solely rely only on predefined methodologies or previous solutions to similar problems. Though approved design knowledge is often re-applied to specific sub-problems, overall approaches in architectural design are typically experimental. To avoid undesired side- or after-effects, architects takes on the responsibility to evaluate all known factors involved in a design project that might lead to unwanted outcomes in both physical (structural, functional) and ethical (social) sense. Architectural problems are complex and characterized by a wide range of determining, partly unknown or subconscious factors on various levels, ranging from local building codes to aesthetic aspects. Architects and designers are experienced in solving these problems, which due to their complexity require the architect's reasoning, guessing as well as intuitive decision-making.

Defining and understanding given design problems requires conceptions of possible solutions: information needed to understand a problem depends upon the designer's idea for solving it [19]. Conceiving and developing a solution scenario at the same time is tied to a conception of the future: During design processes, images of a desirable future are developed in order to guide a process of planning and action that will eventually approximate a selection of those images. Design processes are to some extent directed towards utopian design ideals, which develop out of predictions as well as desires and hopes.

Today, generative techniques are primarily applied to the challenge of generating variance during a design process (see for example Spuybroek, *Off the Road – 5speed*, in [1], pp. 56-61). Even though sets of possible solutions can often be easily determined (automatically generated), human selection is typically still needed to pick the most appropriate one(s) (see [8]). This can be (at least partially) explained with responsibilities resulting from unpredictable – complex – consequences of design decisions. In the context of this challenge, complexity theory can offer valuable insights. Due to lacking social and contextual knowledge and reasoning capabilities, computational systems are not (yet) put in charge of bearing such responsibilities. To direct generative processes and to evaluate and select from variants, feedback from the human architect is hence still required. Generative systems that are yet designed to select from generated sets commonly follow one of the following two strategies. They either use sets of general constraints to regulate generative processes, as for example selection criteria in evolutionary design systems. Such sets are often highly simplified and to not necessarily embrace all relevant aspects of functional/structural/social etc. responsibilities. They are hence mostly found in experimental settings or as explorative aids in early design stages. The other strategy retains generation and variance selection merely to superficial, e.g. ornamental design aspects, which are unlikely to produce unpredictable and hence undesired complex interferences with a building's functions. A potential third, more open strategy might be possible: this strategy draws on complexity theory and will be discussed in the following.

3. Complexity Theory

Within the past three decades, complexity theory has evolved from describing properties of specific given systems into a broad area of research in science with applications ranging from economics to physics. Since there is currently neither a consensual general definition of complexity nor a unified theory, complexity as a scientific interest is best explained in relation to the history of the field [11]. Complexity theory as a scientific area of study developed as a response to Newtonian linearity being the exclusive scientific paradigm, coupled with a reductionist approach prevalent in science until recently [18]. Newtonian science is based on the assumptions that physical and mathematical laws are essentially simple and straightforward like the ones proposed in Newton's *Principa Mathematica* in 1687. Time is assumed to be irrelevant to natural phenomena, so that all processes are entirely reversible. During the 20th century, these views have been challenged by a number of theories and discoveries, first of all Darwin's evolutionary theory, followed by Wiener, von Neumann and many others. Time has been discovered to play an essential role in irreversible processes, resulting in a renewed interest in history as determining the present (see [6]).

In addition to linear (and therefore strictly predictable) phenomena, complexity theory has opened up views on the tangled and more complicated causalities involved in systems formed by large numbers of interdependent elements. Complexity is observed in systems where many independent and varied elements interact in intricate organisational configurations, typically in a massively parallel manner. Examples include chemical reaction cycles, anthills and cities. Typically, complex systems are *open* – receiving or exchanging energy with their environments. Thus, complex systems are able to display complicated dynamics unlike energetically *closed* systems that will settle into stable equilibria. While it describes the qualities, not the quantities of a particular type of system (given systems can be characterized by its compositional, structural and functional complexity), complexity theory does allow for general statements about the system's behaviour. Among the most characteristic properties of complex systems are self-organisation, nonlinearity, threshold phenomena or unstable equilibria (see [16]). A complex system's properties are relative to the observed scale – to study a single ant, for example, does not reveal the dynamics of an entire anthill. Thus, complexity theory serves as general description framework for many phenomena observed from more holistic scientific viewpoints. It represents a theoretical foundation to a vast number of more specific scientific fields, such as dynamical systems theory, fractal or recursive relationships, thermodynamics, and many others. These strategies are used as toolbox in generative design approaches.

Though definitions of complexity are numerous, rather vague and general, Rescher summarises characteristics of complexity as follows (see [20], p. 9):

Modes of Complexity:

Epistemic Modes: Formulaic Complexity
- Descriptive Complexity (length of the necessary amount of description)
- Generative Complexity (length of the recipe needed to produce a system)
- Computational Complexity (time and effort involved in solving a problem)

Ontological Modes: Compositional Complexity
- Constitutional Complexity (number of elements in a system)
- Taxonomical Complexity / Heterogeneity (number of types of elements in a system)

Ontological Modes: Structural Complexity
- Organisational Complexity (different modes of interrelationship between elements)
- Hierarchical Complexity (elaborateness of hierarchical relationships)

Functional Complexity
- Operational Complexity (variety of modes of operation or functioning)
- Nomic Complexity (elaborateness and intricacy in the laws governing a system)

3.1 Complexity and Prediction

Classical science relies on a linear world model, which renders predictions relatively exact and easy to make. With the rise of complexity theory, these views had to be adjusted. While simplified versions of reality may be described using traditional linear explanation models, the greater part of observed phenomena cannot be reduced to simple elementary behaviours without losing their essential characteristics. This sensitive dependence on environments renders complex systems difficult to isolate, model or reproduce for experimental purposes. Nonlinearity and their characteristic dynamics render complex systems hard to predict in the short term, and impossible in the long term – a well-known example for this problem is weather forecasting. However, complexity theory is also applied to prediction tasks (see [23]). Since complexity theory shows how limited possibilities of predicting dynamical systems are, there cannot be any case-based predictions related to specific future situations. Instead of exact, case-based prediction, an alternative based on stochastic observations is used: In order to characterize a system's ability to resist and adapt to external disturbance, system models are developed with as much detail as possible. These models are then tested for stability against random changes within simulated environments. Thus, predictions for complex systems are mostly based on identifying a specific system's properties in general rather than predicting their exact future state or behaviour. Predictions are therefore based on statistical evaluations and large numbers of samples, and – similar to other statistical methodologies - only describe probabilities of future developments. As is known, though probabilistic data suggests prospective projections, it is not an entirely reliable planning basis.

4. The Relationship of Architecture and Complexity Theory

Complexity theory emerged out of a changing scientific context brought on by the general realisation of the shortcomings of classical Newtonian science. Rather than presenting completely new discoveries, complexity theory offers a new viewpoint on many known, but hardly understood phenomena, in particular those patterns and processes found in nature. Natural patterns and growth processes often exhibit emergent order, which can be observed at different scales in societies of elements that act in a massively parallel manner. In architecture, naturally grown structures have long been appreciated and imitated, often attributed with a presumed affinity to human beings (see [12]). This appreciation, however, was overpowered by modernist thinking, which condemned complex structures in favour of simplistic approaches. After a century of linearity and determinism in science and technology, the change of perspective on complex phenomena allows architects to reconsider growth processes in architecture, e.g. city development and building morphologies. Besides an interest in aesthetics derived from natural types of order, architects as well as engineers have explored ways of joining bottom-up approaches with the top-down planning requirements of stability and permanence (see [2]). For the extension to the Victoria and Albert Museum in London, Balmond refers to chaotic spirals to develop a columless form and structure.

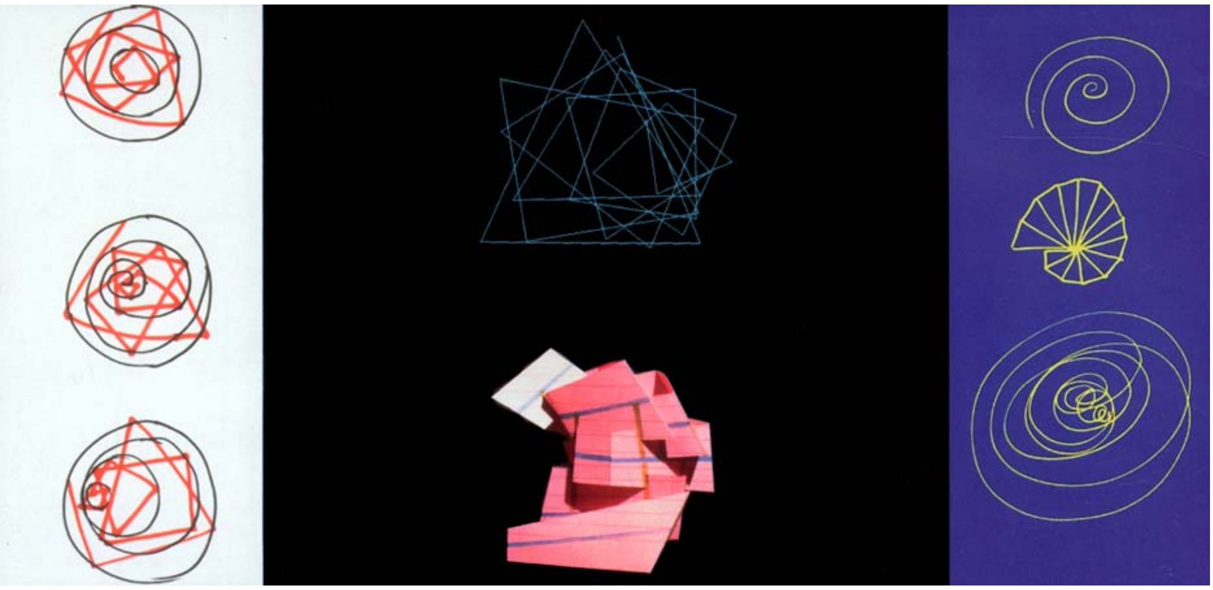

Figure 1: Cecil Balmond: Victoria & Albert Museum Extension (with Daniel Libeskind)

Architecture relates to current interests and views dominating society, and generally perceives its role as reflecting and propagating scientific and cultural paradigms [10]. While architectural modernism developed out of a fascination for machines, technology and science, it also inherited many problems resulting from over-generalisation of design problems. Architectural movements since the 1960s have attacked modernism for this reason, but it still holds as the dominant paradigm in architecture. Even though architects have introduced complexity theory into the architectural discussion, traditional ways of thinking and designing have not changed much. Architects typically use top-down design strategies, since this is thought to ensure efficiency, economy and control in developing design solutions. Order as found in complex systems, on the contrary, develops without planning out of bottom-up processes [13]. Since architecture traditionally uses the former approach to design, most references to complexity theory have so far been retained to a metaphorical or iconographic level.

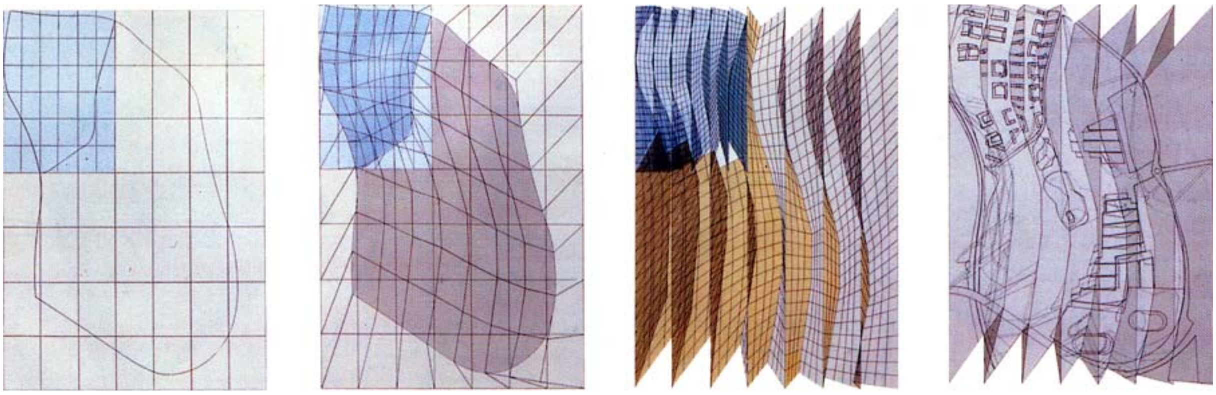

Figure 2: Peter Eisenman: Rebstock Park (Frankfurt) Masterplan, 1993

In his masterplan for Rebstock Park (Frankfurt), Eisenman uses folding metaphors in his design approach, graphically and metaphorically referring to diagrams derived from catastrophe theory that describe sudden changes in dynamic system developments (see figure 2). Showing an even more iconic approach, Jencks (figure 3) refers to complexity theory by directly translating diagrams and images depicting strange attractors and other complex phenomena in the design of his landscape architecture.

Figure 3: Charles Jencks and Maggie Keswick: Garden, Dumfriesshire, Scotland.

However, architectural problems usually involve complexity in the form of surrounding city fabric, building techniques, politics and unpredictable changes in the course of design processes, communication and building life. In order to make use of complex forms or systems in architectural design, tools are needed that can handle complex forms or relationships. Generative architectural design developed as an answer to these needs. When comparing the history of generative architectural design with Rescher's [20] modes of complexity, close parallels become obvious. Most applications of generative architectural design in the past have focused on variations or combinations of constitutional and taxonomical complexity in generating variance (e.g. L-systems, shape grammars, parametric design, data mapping techniques and the like). As an example, figure 4 shows a roof structure based on the generation of a large number of simple elements constrained by a continuous global alignment rule.

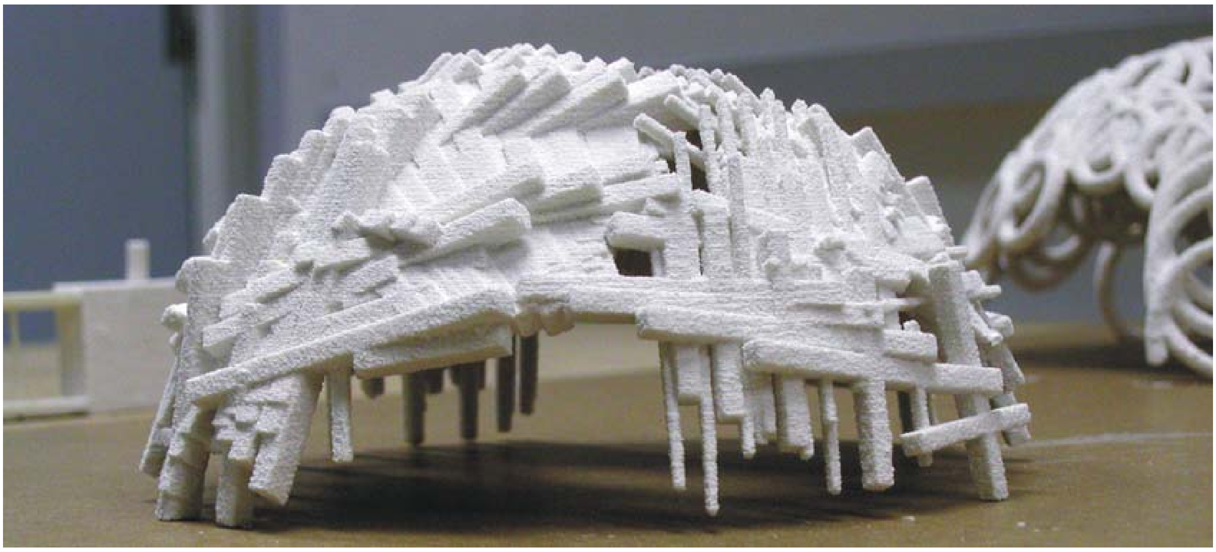

Figure 4: Generated roof structure (rapid prototype)

Only few generative architectural design approaches deal with other kinds of complexity such as evolutionary design or cellular automata. While there are generative approaches to hierarchical and operational complexity (e.g. emergent and self-organizing systems), they have not been used in architecture yet.

4.1 The Dilemma of Generative Architecture and Complexity Theory

The central conflict between architectural design and complexity theory is a consequence of the nature of both disciplines: scientific theory is an inter-subjective tool to observe and explain, while design is the exact opposite in employing not only rational thought but guesses, emotions and feelings to prospectively create personally preferred solutions to given problems. Complexity theory is mainly employed in retrospective analysis in order to find causes and relationships in complex phenomena such as in meteorology or in economics, while its predictive capabilities are rather limited. Complexity theory is constrained to probabilistic predictions based on general rather than specific cases. In complex architectural design projects, this contradiction is nothing new. Designers of all disciplines deal with uncertain and vague conditions and have to rely on science as well as guesses and human intuition to achieve results likely to work. As a result, design processes may be understood not as a rational 'thinking before acting', but a more human-centred 'feeling and thinking while acting' (see [17]).

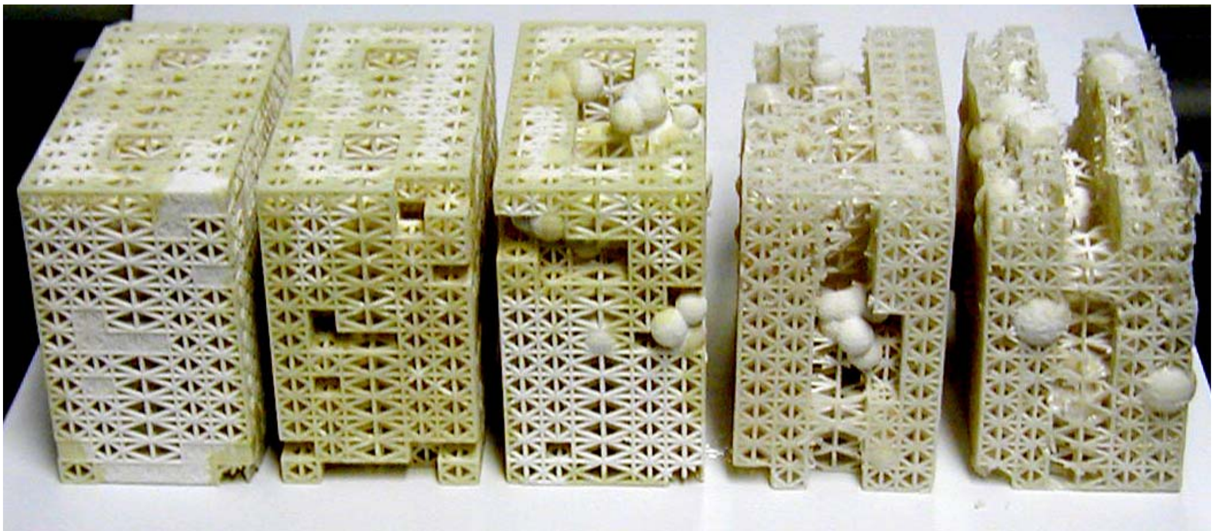

Figure 5: Generated grid structure at various stages of digital decay (rapid prototypes)

While architects are used to design for complex problems, the general method of dealing with complexity is to generalize and impose simplified structures onto complex contexts in top-down design processes. Design solutions produced in this way typically lack relationships and interfaces relating them back to their environments. Emergent natural order, on the contrary, derives its coherence entirely from large-scale contexts, but is not directed, since it develops without planning. The generated digital decay shown in figure 5 describes an additive and a simultaneous subtractive growth process, both progressively infesting a linear (modernist) grid structure. The state of a complex system is produced by sets of conditions and constraints, which are created by chance and may change over time. A fundamental dilemma between both notions of order emerges: How can architecture combine the richness and dynamics of emergent complex order with the economy and control of traditional top-down planning methods? And how can the application of emergent order in architecture meet the social responsibility of planners?

In addition to the question of control, complex phenomena have introduced the necessity of considering time in architectural design. Although movement has been an architectural topic for a century, it has been considered mainly in relation to building form and composition. Firmness and permanence have remained the dominant aims in architecture, and time has not been reflected in architectural design until recently (see for example [15]). While time and change are used in design processes today, this has not changed architects' belief in firmness and permanence. A further step into the understanding of complexity theory will enable architects to see buildings as dynamic elements in dynamic environments. Until today, architects have only seen activities within and around buildings as dynamic elements in architecture (see Tschumi, B.: Responding to the Questions of Complexity, in [3], pp. 82-87). Societies, economies and most aspects of daily life increasingly become connected and interdependent. Materials, appliances and inhabitants inside buildings behave in complex ways. Architecture, along with all other professions, will have to face these tendencies and find new solutions to the resulting open and dynamic problems. In this context, generative architectural design systems will have to develop into design as well as simulation tools, working with complex relationships of elements and simulating change over time.

4.2 Architectural Design and Metaphor

Design methodologies have to account for the risks arising out of a lack of predictability. To tackle this problem, architects traditionally rely on vague bodies of knowledge formed mostly through experience. This knowledge includes previous solutions to certain classes of architectural problems as well as personal methods to develop solutions for previously unknown problems. Since architectural design problems are unique, there is only very limited systematically accumulated and common methodology. To deal with and communicate about design problems, architectural design uses metaphors as guidelines. Metaphors can be used to describe situations in general, to describe intended design outcome and to serve as guidelines as well as ways of understanding. They can be shared and communicated, used to explain and still be interpreted individually. Well-known examples are the metaphors determining Modernism's understanding of architecture: 'open plan', used by Wright, or the famous 'houses as machines for living' as proclaimed by le Corbusier.

Metaphors arise from and convey a view of reality, influencing activity and ways of thinking in design response to reality - solving problems simply means representing them so as to make the solutions transparent [21]. Guiding metaphors, shared and communicated in architectural design contexts, change over time, reflecting general changes of (economic, social, or scientific) situations. Changes in the conceptions of role, power and functionality of architecture are usually accompanied by a rethinking and (re)invention of design metaphors (see [14]). Generative design tools also develop from design metaphors, reflecting perceptions of design problems as well as a paradigm's shortcomings.

4.3 Complexity Theory – a New Toolbox for Architectural Design?

As a scientific tool for analysis and description, the direct applicability of complexity theory as a new design method appears rather limited. Neither can it be used as a precise tool for prediction, nor does it provide immediate guidelines to design. Understood in a more fundamental way, though, design perspectives are changing due to the influence of complexity theory. Besides rather indirect changes to human viewpoints, however, generative architectural design may implement principles derived from complexity theory in more specific ways. Generative tools cannot predict the outcome of specific complex design projects, but they might well be useful in approaching or evaluating solutions by giving an impression of complex systems' properties when faced with changes in their environments. The modes of complexity mentioned by Rescher [20] suggest future directions and challenges to generative architectural design. Future generative architectural systems will have to facilitate elaborate hierarchies of elements and allow for a broad range of functional complexity properties involving change over time. Massively parallel modes of communication, interaction and feedback structures between design elements will be of particular importance.

Complexity theory shows that in all complex scenarios, long-term predictions are impossible: no scientific theory can yield certain predictions for unique design problems. As a possible reaction, architectural designers might focus more on the ability of their products to cope with challenges of an essentially dynamic and unpredictable future. Problems arising out of complex situations often have more than one possible outcome. Therefore, generative architectural design might consider designs that are relatively open or 'unfinished', so that architectural solutions are not determined by past predictions or guesses but by actual future events. These characteristics have been associated with 'living buildings', and envisioned by Frazer [9] as a future direction of generative evolutionary architecture.

By realizing the complex nature of architectural problems, architects will need to use new metaphors, expanding traditional paradigms in architecture to accommodate new concerns. These include unconventional hierarchies, energy and communication flows as well as elements with certain degrees of freedom to adapt to change. Central to a more flexible and adaptable architecture is the organisation of infrastructure and communication as dynamical elements that connect with and react to the environment. In this context, generative architectural design offers ways to handle complexity, but new approaches to work with and manage complex systems are required.

5. Conclusion

The introduction of complexity theory into architectural design has several motifs. Besides an interest in new aesthetics, architecture seeks coherence with social and scientific viewpoints. Complexity theory offers a new view on natural phenomena – including human activity – and encourages hopes for a more natural and humane quality in architecture. Rather than imposing over-generalized systems, architecture needs to acknowledge complex, interconnected and changing realities. In the context of complexity theory, the prevalent idea of stability in architecture needs to be reconsidered: in environments that change rapidly due to networked parallel activities, permanence will have to mean the ability to adapt to changes.

Complexity theory does not yield a specific methodology to design, but it can be used to understand and deal with problems arising out of complex design tasks. The unique and complex nature of architectural design problems limits predictability of a solution's success, but complexity theory may aid in estimating a solution's appropriateness in the context of a changing environment. In a complex world, the process of design is never finished – design products need to be able to communicate, adapt, exchange and communicate after the design process has ended. Since design processes will continue throughout the lifetime of a building, generative design tools and their products will have to merge to some extent.

A central challenge to architectural design emerging from complexity theory is the question of control: while traditional design processes use generalizing but directed top-down control, complex systems are driven by massively parallel, non-directed bottom-up mechanisms. In order to use complexity in architectural design, ways have to be found to integrate both modes of control as well as providing the necessary open communication protocols. Generative architectural design systems of the future will have to deal with new modes of control, massively parallel dynamics as well as a changed view of time and predictability.

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GenOrchestra: An Interactive Evolutionary Agent for Musical Composition

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Abstract

GenOrchestra is a project involving the Dipartimento d'Informatica and Conservatorio di Musica "N. Piccinni" in Bari. This project concern a Creative Evolutionary System, based on Evolutionary Computation (EC) techniques, applied to the field of western tonal music. With GenOrchestra a novel way to evaluate the produced tunes is presented: indeed we adopt a hybrid solution composed for two kinds of fitness functions. The first, called **technique fitness**, evaluates the consonance degree between melodic, harmonic and rhythmic sections, moreover, it defines how well the rhythmic paths is organized into a coherent musical event. The second fitness function called **human fitness**, determine how well the tunes are perceived from a human audience, like in a concert. This task is accomplished by presenting the tunes on the Internet and then gathering the surfers evaluations in a database from which the system take the final population scoring. This, coupled with a no limited musical primordial soup, makes GenOrchestra a promising eclectic artificial composer. The ultimate goal of this project, currently in progress, is the development of a very human-like composer, which can produce music in any musical genre, and which is able to show a "personal style". Samples will be soon available at http://valis.di.uniba.it/GenOrchestra/samples.html

1. Introduction

Today, many systems exist which exhibit human behaviors: from natural language dialogues abilities to art production and feeling expression. Several examples can be found in music [4]. One of the most cited is GenJam, developed by J.A. Biles at Rochester Institute of Technology, GenJam (Genetic Jammer) is an interactively G.A. (IGA) that evolve jazz solos on a given chord paths and is able to duets with human players connected with the system via Midi.

Another interesting system is Conga, developed by N. Tokui of Tokyo Institute of Information and Comunication Engineering and professor H. Iba of Graduate School of Frontier Sciences of Tokyo University. Conga is an interactive system that, combining GA and Genetic Programming (PG), evolves bass/drum rhythmic sequence.

Vox Populi, developed by A. Moroni, Technological Center for Informatics, J. Manzolli, F. Zuben and R. Gudwin of University of Campinas, Vox Populi is a real time music composer that generates a chord coded into the MIDI standard and then evolves it by using the GA paradigm.

In this paper we present a project, involving the Dipartimento di Informatica of the University of Bari and the Music Conservatory "N. Piccinni" of Bari, aimed to the development of an e-

learning web system applied to the field of western tonal music. Currently we have developed the sound engine called GenOrchestra (**Gen**etic **Orchestra**). GenOrchestra is based on a Genetic Algorithm (GA) [6] and presents some modification of the standard GA paradigm. The aim of Genorchestra is the automatic tunes composition, starting from parameters concerning the structure, the number of measures per section, the starting beat, the playing tempo and starting scale. These parameters will be set by the user or automatically chosen by the system itself, by means of pseudorandom rules.
The remainder of the work is structured as follows: Section 2 and 3 describe in more details the GenOrchestra general architecture and the underlying genetic algorithm. In Section 4 the fitness function adopted in Genorchestra is discussed while in Section 5, some results are reported. In Section 6 we briefly describe how to integrate human evaluations with the genetic algorithms evaluation and, finally, in Section 7 some conclusions are drawn.

2. The Architecture of GenOrchestra.

The GenOrchestra underlying evolutionary process has to be an Open-Ended one, i.e. a continued evolution to relative maximum points without nor temporal ending neither evolution to a single absolute maximum point. The main feature of the system is its generality concerning the faceable musical genres and the capacities of self-judging the composed tunes by evaluating the melodic, harmonic and rhythmic qualities based on the ordering of consonance of musical interval. The aforesaid evaluations procedures are integrated with the web surfers and expert human composers evaluations, through the GenOrchestra site. The repeated iteration of these phases should make emerge particularly ways to equilibrium points, to an intelligent musical behavior, to a “style”.
The general architecture is composed of six modules (Fig. 1):

- **Composer**: this module handles the system compositional process. It receives the tunes features and the GA parameter from the user and then starts the evolution. This module is strictly correlated with the Maestro module giving it the composed tunes and receiving from it the fitness scores. Moreover, the Composer communicates with the Feedback module for the user evaluation of the tunes.
- **Maestro**: This module embeds the overall consonance fitness functions. Input to this module are the user tunes submitted via web and the tunes produced by the Composer. The Maestro module produces as output the relative fitness scores.
- **Feedback**: The Feedback module is responsible for the human evaluation of composer tunes. It shows the produced tunes on the web, retrieves the surfers evaluations, defines the scores per tunes and sends these values to the Composer module.
- **Arranger**: The Arranger takes the user tunes, submitted via web, and applies musical transformations in order to arrange the musical materials.
- **Learning**: This module handles the pure documentation side of the whole system. It handles the Docs database in which downloadable materials, concerning music theory and computer music, is stored. This module makes a search in the database following the user query.
- **Web Site:** It makes up the system Internet interface; through this interface users can listen the music produced and they can evaluate it, explaining the evaluations through the guestbook and, so, influencing the future musical production.

The Composer module is mainly based on genetic algorithms [6]. Many variations to the original GA paradigm have been proposed in the last years; GenOrchestra is based on a Steady-state GA with tournament selection and multi-cut points crossover. In a Steady-state GA, every new population presents an overlapping between the old and the new generations. In the tournament selection the population is grouped in several individual families, the best two individuals of each family mate with the crossover operator and the new solution substitutes those in the family with worse fitness. Concerning the crossover operator, GenOrchestra applies a multi cut points operator. In our implementation, a cut point is chosen

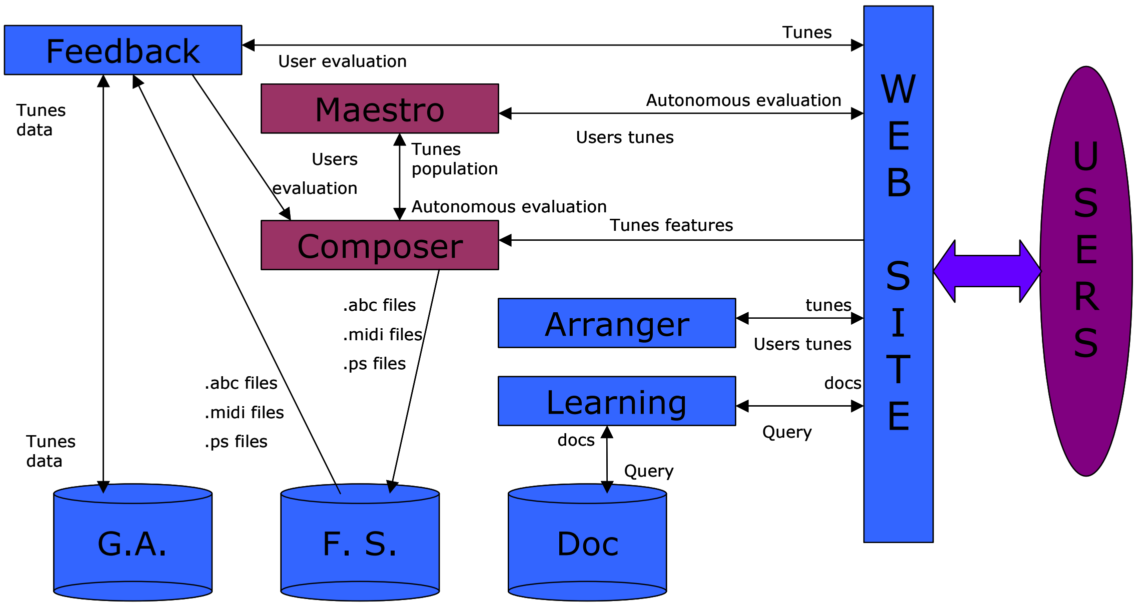

Fig 1. The general architecture of GenOrchestra

for every section in the tune structure and for every layer. The cut point has not been chosen at low level (such as the note or the chord), but at the measure level to avoid the production of new individuals with length measure that differs from the parents one.

3. The chromosome representation in GenOrchestra

In the genetic algorithms, the representation of a solution is usually called the chromosome. The goal of GenOrchestra is to continually evolve populations of tunes, so the chromosomes have to reflect the structure of a musical piece. We can simplify a piece of music as a significant set of sections, differing each other by the melodic theme and possible scale, time and beat variations. Every section can be repeated in the tune execution so if we have three sections, A, B and C, then the structure can be any disposition with repetition of these three sections. Furthermore a tune has some initial features such as: Scale, beat, note unit length (eight note, half note etc.) and playing tempo of the note unit length. These values can be different in a given section and from section to section. Every section is made up of a certain number of measures; a measure is a not unique set of notes where the overall length is equal to the beat value. What we hear in a piece of music is, usually, made up of three sonorous layers: a bass layer, a harmonic layer and a melodic layer. In the first layer we have the bass score, in the second layer we have the chords score and in the last one the tune theme or solo score. So, the chromosome is defined as an array made up with so many components as the

sections in the structure, each of these components points to a three-layered structure containing the aforesaid scores.
The chromosome generation starts from the initial scale; on the ground of this scale the initial chord is built up with a random generated length that cannot exceed the length of the measure. On this first chord a melody with the same length and bass score is generated, then a melodic note is randomly chosen for a new chord with the same initial scale. This process is repeated till the length of the measure is reached; then it is repeated for the number of measures of the current section and for any section of the tune (see fig. 2).
On the ground of the described chromosome, we decided to adopt the same approach as in [1] for the mutation phase that is musically meaningful mutations operators that work at measure

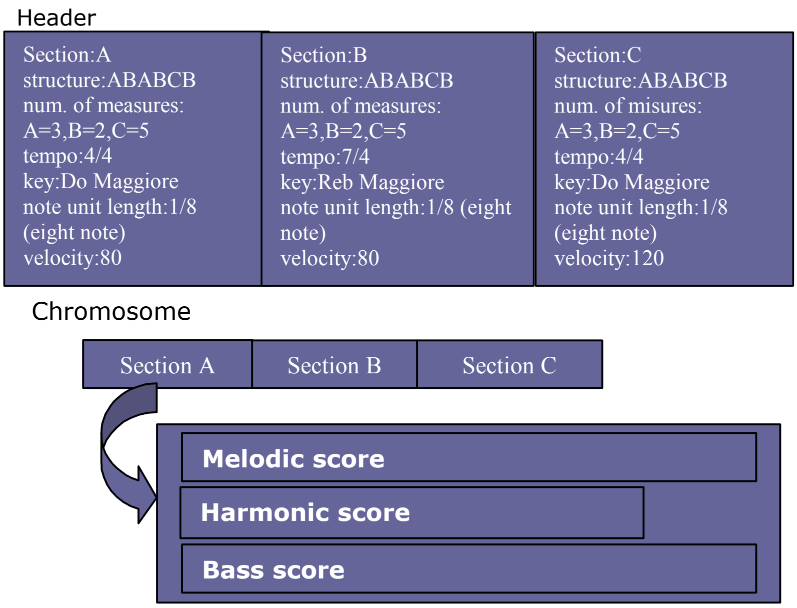

Fig. 2 Chromosome structure for a three-section tune

level. These operators implement classical compositions techniques. With a given mutation probability a chromosome is scanned and measures are chosen for the mutation in every layer. The mutation is randomly chosen among the following 6 types:

- Transposition: Transposes notes and chords in a measure, by a random number of intervals in the given scale. If a note is transposed beyond the allowed range, the count continues according to the scale interval in the upper octave, ignoring rests.
- Reverse: Reverses the events in a measure, rests included.
- Rotate–right: Rotates the events in a measure by a random number of positions to the right.
- Invert: Given an event in the measure, it evaluates the difference between the top position scale note (7) and the scale position of the current note.
- Sort up and sort down: sort the measure and preserve the rhythmic structure
- Invert-reverse: Given a measure, the invert and reverse operators are applied consecutively.

4. The autonomous evaluation of chromosomes

The fitness function used in GenOrchestra is a hybrid solution formed by an autonomous evaluation, judging the consonance qualities among melodic, harmonic and bass layers and a human evaluation for the aesthetic qualities. This approach would be a suitable solution to a critical phase in every musical GA. Indeed actual systems implements the fitness phase by two ways:

a) Completely delegating the individual evaluations to the human ears: this leads to great human-like musical production, but make up a heavy bottleneck for the system and a dull work for the human judge.
b) Adopting autonomous solutions like neural networks [2], implementing physiological aspects in listening music [7] and completely removing the fitness phase [3].

None of these solutions fit the GenOrchestra general purposes but the former resolve the drawbacks of the latter. So, a hybrid solution seems to be a good alternative, moreover it best reflects what happen in the real world.

Indeed, the GenOrchestra consonance fitness function is:

Consonance fitness = melodic-harmonic consonance score + harmonic consonance score + bass-melodic consonance score + bass-harmonic consonance score

To develop the fitness function we start from the fuzzy approach described in [7, 8], where a consonance measure among notes in a chord was defined and we extend it to a consonance measure of notes over chords. By means of this approach we can represent a note as a compound tone consisting of its fundamental tone and upper harmonic series tones. It can be represented as a fuzzy set in which the membership degree of a given tone is proportional to its amplitude. Finally, a note is a fuzzy set made up of couples (x, y) in which *x* is a tone (also called partial), and *y* is the related weight in the note, corresponding to its amplitude. We can now define the consonance between two notes Sm and Sn as follows:

$$(3.4.1)\ Co(S_m, S_n) = \sum_{(x,y)\in S_{m\cap n}} y \qquad (1)$$

The consonance measure between two notes is intended as the sum of the intersection of the partials weights, in the range [0,..,1].

Starting from this concept we have defined a set of evaluations to carry out the overall consonance of the tune. We can formalize a note as a couple (pitch, length) and a chord as a set of three notes of the same length but with differing pitches. So, if we have a melodic series of notes $M=\{(m_1,t_1),...,(m_n,t_n)\}$, a series of harmonic set of chords $H=\{(A_1,t_1),...,(A_d,t_d)\}$ where $(A_d,t_d)=\{(a_1^d,td_d),(a_2^d,t_d),(a_3^d,t_d)\}$ and a bass series of notes $R=\{(r_1,t_1),...,(r_z,t_z)\}$, we can define several consonance score functions:

- note-chord consonance score:

$$NC(p, A_d) = \frac{\sum_{i=1}^{3} Co(p, a_i^d)}{3} \qquad (2)$$

, where p is the pitch note;

- chord-chord consonance score:

$$CC(A_i, A_{i+1}) = \frac{\sum_{j=1}^{3} NC(a_j^i, A_{i+1})}{3} \qquad (3)$$

- melodic-harmonic consonance score:

$$F_M = \frac{\sum_{j=1}^{d} \frac{\sum_{i=1}^{n} NC(m_i, A_j) * t_i}{t_j}}{d} \tag{4}$$

- bass-harmonic consonance score:

$$F_R = \frac{\sum_{j=1}^{d} \frac{\sum_{i=1}^{z} NC(r_i, A_j) \cdot t_i}{t_j}}{d} \tag{5}$$

- melodic-bass consonance score:

$$F_{MR} = \frac{\sum_{i=1}^{n} \frac{\sum_{j=1}^{z} Co(r_j, m_i) \cdot t_j}{t_i}}{n} \tag{6}$$

- harmonic consonance score:

$$F_H = (\sum_{i=1}^{m-1} CC(A_i, A_{i+1})) + CC(A_1, A_m) \tag{7}$$

- total consonance score:

$$F_C = F_M + F_H + F_R + F_{MR} \tag{8}$$

Using these functions we carried out the consonance degree between every chromosome layers.
Lets now describe the basic concepts and the resulting function for the rhythmic evaluations of the tunes composed. When we listen to a piece of music we naturally organize the sound signals into meter groups. Furthermore, we infer a regular pattern of strong and weak beats to which relate the actual musical sounds. GenOrchestra evaluates these patterns to judge how well the tune matches the metrical structure defined by the starting meter input. It must be emphasized that beats do not have duration, and we can think about them as an idealization, used by the performer and inferred by the listener from the musical signal. To use a spatial analogy: beats correspond to geometric points rather than to the line drawn between them. But, of course, beats occur in time so an interval of time takes place between successive beats. For such intervals we use the term time-span. Because of the afore said analogy, we can represent beat by dots.

a) . . . . . .

b) . . . .

Fig. 3. Beats sequences examples

The two sequences differ in a crucial respect: the dots in the first sequence are equidistant but not those in the second. The meter function is to mark off, insofar as possible, into equal time-spans, this disqualifies the b) sequence from being called metrical. Another aspect of meter is the notion of periodic alternation of strong and weak beats, in a) sequence no such distinction exists. For beats to be strong or weak there must exist a metrical hierarchy. The relationship of strong beat and metrical level is simply that, if a beat is felt to be strong at a particular level, it is also a beat at the next larger level. This is shown in the following figure.

Beats	1	2	3	4	1	2	3	4	1
	.	.	.	.	.	.	.	.	.
	.		.		.		.		.
	.				.				.

Fig. 4. Metrical structure for a 4/4 meter

So, given a note unit length and a starting meter we can built up the relative metrical structure as follows:

- Define a first note unit length level formed by a number of beats calculated by the following formula:

$$beats = round\left(\frac{num\_val * val\_mov}{unit}\right) \tag{9}$$

  Where *beats* is the number of beat per level, *num_val* is the number of movimento per meter, *val_mov* is the value of the meter, the *unit* is the note unit length and, finally the *round* function round up the ratio result to the next integer, if it is a float.
- While *beat* is greater or equal to 1:
  - Duplicate the *unit* and then calculate the (9) again

We referred to this structure as **perfect metrical structure.** Given this structure, we defined the metrical patterns for every measure in a given tune defining how many pitches start time occur in a given time-span. We refer to this pattern as the **actual metrical structure**. Then the closer the **actual metrical structure** to the **perfect metrical structure** is the better the evaluation.

5. Experimental results

To verify the effectiveness of the GA in evaluating the produced tunes, we performed three different experiments. In the first set of experiments we fixed the parameters concerning the tune features, as described in Table 1 and set different values for GA parameters, as reported in Table 2.

For each configuration of GA parameters, we performed 10 runs with the same population size (100 individuals) but with different initial population. The stop criterion was the

Tune features	***Values***
Structure	**A**
Measures num.	**10**
Beat	**4/4**
Tempo	**40**
Note unit length	**Half note**
Starting Scale	**C Major**

Tab. 1 Tune features for the first experiment

Experiment	*Crossover Prob.*	*Mutation Prob.*	*Generations*
1	0.7	0.2	100
2	0.5	0.2	100
3	0.7	0.3	100
4	0.5	0.3	100
5	0.7	0.4	100
6	0.5	0.4	100

Tab. 2 GA parameters for the first experiment

maximum number of generation allowed (100 in our experiments). The evolution to an effectiveness euphonic music production has been tested with the help of a human composer.

As Table 3 shows, the best results have been obtained in the second run, corresponding to a crossover probability equal to 0.5 and mutation probability equal to 0.2. Figure 5 plots the trend of the fitness with respect to the number of generation for the best resulting run. As it can be seen, in the first 50 generations the algorithm evolves very quickly and the fitness increment is near equal to 0.8, while in the second half of the run, the algorithm is quite stable. Tunes produced in the initial population shows very disorganized paths with frequently changes of note and chords lengths, while the best tunes in the last generation show a more relaxed musical events distribution and an effectively more euphonic theme.

Experiment	***Generation***	***Best Fitness***	***Average Fitness***
1	83	1.157228	1.070756
2	**96**	**1.384570**	**1.275823**
3	92	1.202566	0.971285
4	88	1.199713	1.002079
5	49	1.156400	0.935947
6	65	1.035057	0.815731

Tab. 3 Results of the first experiment

In the second set of experiments we used the best the GA parameters found in the first experiments (crossover probability=0.5 and mutation probability=0.2), and set different values for the tune features, the beat values were 3/4, 5/4 and 7/4, the tempo values were 4 and 8, while the values for the other features remain the same of the previous experiment.

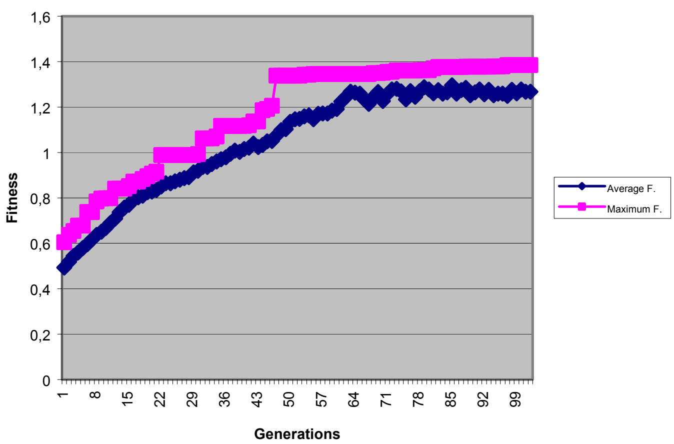

Fig. 5 Best run of the first experiment

For each configuration of tune features we performed 10 runs with the same population size (100 individuals) but with different initial population. As in the first experiment, the stop criterion was the maximum number of generation allowed (100 in our experiments), and the evolution to an effectiveness euphonic music production has been tested with the help of a human composer. As Table 4 shows, the best results have been obtained in the sixth run, corresponding to a Beat of 7/4 and a Note unit length of 8. Figure 6 plots the trend of the fitness with respect to the number of generation for the best resulting run. As the figure shows, in this run the evolution is faster than in the preceding experiments (the maximum fitness value is near 2.0 within the same number of generations). Furthermore, from the graph it can be seen how the maximum fitness score is reached at the end of the evolution, with the possibility of a more high values with more generations.

Experiment	***Generation***	***Best Fitness***	***Average Fitness***
1	98	1.104048	1.007800
2	95	1.172145	1.090072
3	96	1.101545	1.044355
4	95	1.326399	1.158015
5	96	1.244252	1.146731
6	**92**	**1.923617**	**1.581887**

Tab. 4 Results of the second experiment

To verify this last statement, we decided to repeat the better runs of the two preceding experiments (plotted in Figures 5 and 6), setting a higher generations number (1000). In these further runs we have reached a better fitness score than in the runs limited to 100 generations, but the slight fitness improvement does not seem to justify the strong time effort required. However, in the last generations more individuals with the same fitness score but with different musical structures have been found. This result is consistent with the Open-ended approach and is justified by the fact that identical consonance scores can be reached with different melodic-harmonic-rhythmic structures.

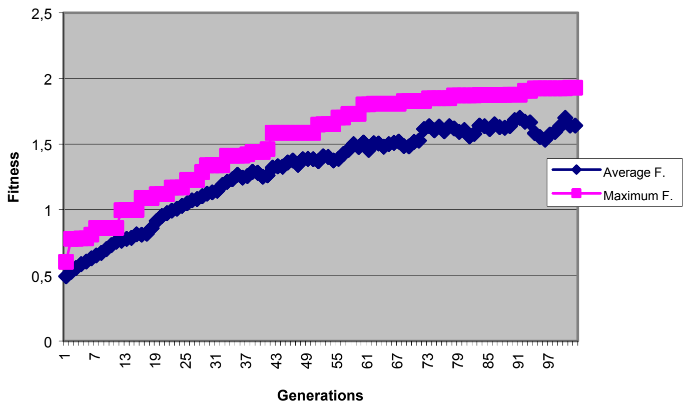

Fig. 6 Best run of the second experiment

6. The human evaluation of chromosomes

The results showed so far refer to the automatic evaluation of the tune features. Nevertheless, a musical composition should be evaluated for its aesthetic qualities. GenOrchestra integrates the GA fitness function with the human evaluations of the produced tunes. In fact, the chromosomes produced by the GA are made available on the GenOrchestra Web site and, users accessing the site, can listen them and provide their subjective scores. Users scores are averaged, for each of the evaluated tunes, and are summed up to the GA evaluations. The involvement of human users is an effective solution to the subjective evaluation of the tunes, but, on the other hand, it represents a bottleneck of the GenOrchestra system, due to the time consuming. To overcome this limitation, we assigned a fixed interval of time for the user evaluation of each generation of tunes. Indeed, not the whole population available on the web will receive a user evaluation for the aforesaid drawbacks. This lead to a speciation of the initial population P after the evaluation phase: the population P_u made up with individuals evaluated autonomously and via web and the population P_t of autonomously evaluated tunes passed unseen on the web. Consequently, each run corresponds to two separate evolutionary processes allowing the selection operator to work on individuals with comparable and homogeneous fitness. The separated populations merge into one after the mutation phase, ready for a new iteration of the GA. It should be noticed that there is no correlation among individuals belonging to the population P_u (respectively P_t), in subsequent generations. Experiments with the web evaluation have been performed in a controlled situation where users are known and their accesses to the site have been monitored. In a few days, we will launch a more wide experiment, allowing the access to the site from the whole Web.

7. Conclusions

In this paper we have described a prototype of an evolutionary based system able to autonomously produce tunes presenting a good consonance degree, as confirmed by a human

expert. However, a main weakness of the system is that the good work of the fitness function adopted is not noticeable to the novice human hear and the produced tunes do not yet correspond to a really human-like musical composition. In the future, several others tunes characteristic have to be studied and formalized into our fitness function.
Comparing GenOrchestra with other creative evolutionary systems we can conclude that it is a more complete system because of its goal (to generate a complete tune) but, on the other hand, currently, GenOrchestra produces a not enough human-like though consonant musical output; in fact a human composer is still needed to arrange the musical output into a finished thematic development.
Further development will be:

- A user tunes consonance evaluation module, by which the system evaluates human composition with the aforesaid function, so an evolution to reach that value can be made.
- Formalization of a given musical genre by means of the above features, in order to make the system able to compose in a given style, without any extensive knowledge.
- Last, we intend to overcome the limitation imposed by the web-based evaluation, implementing an aesthetic wit based on an emotive component, able to emulate a human listener and to feel human-like emotions.

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The Side Effect of a Generative Experiment

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Abstract

This paper discusses the issue expressed in the call for the Generative Art 2002 conference that says: "GA is identifiable as one of the most advanced approaches in creative and design world."
In this paper the value of Generative Art for the art, science and design worlds is described in the reference to a generative experiment. The experiment has been conducted in industrial environment with the aim of defining possibilities for natural interaction of humans with machines. In specific, the experiment examined an option for visual adaptation in accordance to user feedback. In the context of the experiment's outcome the issue of recognizability of Generative Art values is discussed. Generative Art can be identified but is not widely recognized as "one of the most advanced approaches in creative and design world". What makes it difficult for designers to switch to generative thinking and accept immediately Generative Art as the possible way of advancing traditional design methods? And what makes it promising to keep searching for ways of application of Generative Art in contemporary design? Some possible answers, proposed in this paper, aim at contributing to the discussion about the changing role of artists and designers in the contemporary society.

1. Introduction

Generative Art is identifiable as one of the most advanced approaches in the creative world. It is certainly identifiable as such by professionals who investigate this domain in depth. Can Generative Art gain a broader recognition, a wider appreciation and more often usage in art, science and design applications? The most often discussed values of Generative Art focus on *creative* features, such as the big variety of results, the high aesthetic value and the interactive potential of generative techniques. Next to the creative values, there exists also one more important value that is *the integration of domains*. The interdisciplinary character of generative techniques makes Generative Art an outstanding field indeed. This interdisciplinary value that enables sharing of experiences among disciplines is not very common, not as much as it is desirable.

Contemporary artists and designers who work with technology and new media often have difficulties with the definition of the domain of their research or with the unambiguous definition of their productions. Sometimes they cannot even easily say about themselves, if they are artists or designers or scientists. In the context of the discussions around the interdisciplinary techniques, capabilities and needs, Generative Art appears as a coherent stream. And as such, it certainly deserves a broader dissemination and implementation.

This paper tackles upon the integrative character of Generative Art in the three following chapters that try to capture values important for three separate domains - design, science and art. A bit of an insight is given into how the domains communicate and what sort of difficulties they stumble across.

Some examples from a generative experiment conducted by Philips Research in co-operation with Philips Design are used. In order to conduct the experiment, generative software called PAINT was developed. One of its modules, called ShapeEditor, can be considered as a side effect of the generative experiment. It was not foreseen in the project planning, but in the development process it turned out that it is necessary to create it, in order to be able to proceed at all.

2. Design: people want what they like

Generative design allows for the definition of rules of transformation. Transformations might be designed so that, depending on user feedback, each interaction with a computer system produces different results for different users. This is why the conclusions of some previous design research into natural interaction and adaptive systems have pointed to generative design as a potentially optimal technique that could be applied in the adaptive user interface design.

A generative experiment has been set up in order to examine an option for visual adaptation in accordance to user feedback. The research objective was to look for ways of achieving *personalization* in natural interaction of humans with machines. The experiment has been conducted in industrial research environment. Personalization was understood there mainly as a capability of a computer system to match the preferences of an individual user. Matching the preferences is enabled by advanced systems that "know" their users and based on this knowledge, which is being gathered in the interaction process, these systems could adapt so that they could generate results satisfying individual user.

The design issue in this case was to find out how far individual users could influence the final computer image, while putting minimal effort into the interaction. The topic of the experiment was to investigate the interaction process and to find out if visual adaptation is possible so that users could with one gesture of a hand determine the final look of graphical forms on screen. The determination means *user selection*, and similarly to other evolutionary systems it provides quite a chaos that is hard to cope with when working within UI design constraints such as quick system response or clear information structure. The design problem in this experiment was to put some constraints on that chaos. The design idea was to describe the initial population in such a way that would shorten the evolution cycle and that would generate the results that would be less unexpected and more fitting the preferences and aesthetic taste of the user.

The adaptive mechanism designed in the experiment was based on shape grammars and genetic algorithms. The initial design work required an in depth analysis of graphical forms and shapes. The initial, "embryonic" form had to be created as well as graphic elements that define the "adults". The full set of all the graphic elements build up the space that is being searched through by genetic code that selects elements and synthesises the forms based on user interaction.

The prototype made for the visual adaptation test has taken the form of a plane with nine "organisms" exposed at a time. These are shown in the *figure 1*. The plane with figures was used for checking the performance of the genetic algorithms, so this is not the final user interface. In fact, the whole experiment was conducted apart from the potential future application.

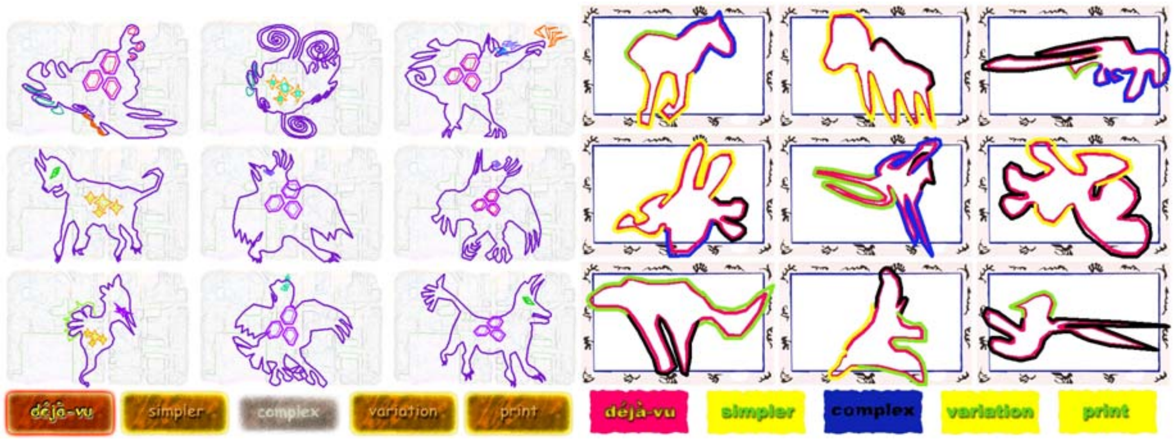

Figure 1: The outcome of the generative PAINT software:

to the left: **The illustration shows the outcome of an interaction session with the PAINT software. From a set of shape grammars a number of forms were generated based on earlier user selections. The "generative avatar" file has 27 embryos of five different species of creatures that in total contain 252 substitution rules at three levels of complexity. The file was used for the exploration of the shape space to find out more and more possible variations of the initially selected form.**

to the right: **The illustration shows creatures that were generated based on the shape grammar set derived from the graphics by Henri Matisse (*The Horse, the Rider, and the Clown*, Plate V from the *Jazz* series, 1947). The "matisseavatar" grammar has 27 embryos and 411 substitution rules at three levels of complexity. It was used to check how quick adaptation towards preferred color happens.**

With respect to the design domain, the work done in this generative experiment seems valuable mainly due to the simple definition of initial user needs. Saying that "people want what they like" was of a help to brake through the stereotype thinking and start looking for natural richness of individualized solutions that are offered by generative design. However, seeing such value was classified as art rather than design point of view. It seems that the user interface design, that in industrial research is dominated by the user-centred approach, tends to produce such clear interaction solutions that chaos (or just richness) produced by generative techniques, although very much natural, is not acceptable as a good enough solution.

3. Science: performance of the code vs. user experience

"People want what they like". Technological reasoning makes it possible to think that it might be conceivable to produce computer systems capable of satisfying individual preferences or even individual aesthetic taste. Preferences can be defined based on earlier choices made. It seems that it could be sufficient to gather information about the choices that users have made under certain circumstances, in order to be able to "predict" their future choice. In the design - research dialogue that has produced the generative software illustrated above, the scientific voice tended to argue that the issue of natural interaction and personalization depends on the system's performance. And that the design, in this case, is a *technically* difficult issue, mainly due to poor performance of existing adaptive (matching) algorithms. Those algorithms aim at enabling definition of user preferences but, in fact, they deal only partially with the big complexity of human needs and wishes.

Science requires measurable data sources. Adaptive and other technologies require high performance of algorithms. But in the domain of user interfaces design what counts is the *user experience*. The notion of the user experience is not really measurable and there is no straight mechanism to relate the user experience to scientific values. In the mentioned experiment, the research was oriented to achieve the maximum system performance, of course to the benefit of the target user. The issue of the user experience was important enough to include the design and art disciplines into the research activities. However, the strongest argument for choosing generative techniques as the research carrier was the fact that genetic programming is acknowledged scientific field.

The final research conclusions drawn from the experiment focused on the weakness of genetic algorithms with respect to the expected performance in a user interface. The main argument against them was based on the slow character of the evolutionary process. The other issue of concern to researchers, this was too many options, too big chaos produced by the generative software. The unique possibility of engaging the domain of art into the industrial research process was of much less importance to scientists. The aesthetic values are not the scientific data, even though these could help to define the user experience.

4. Art: creation

Initially, the generative experiment didn't have any explicit art objectives. The role of artist and designer was to maintain the overall aesthetics of the outcome and to take the humanistic position in the research discussion over adaptive systems and natural interaction. But it might be that this is actually the domain of art that indeed gained in this design-research dialogue and that might benefit most from the outcome of the experiment.

The experiment has used the simplest computer graphics that is 2D outlined linear shapes. The simplicity is a rough condition with respect to visual effects that computer graphics offers. The restriction of dimensions, colors, textures, etc., was assumed to be necessary, in order to learn how to create evolutionary "organisms" that would show *meaningful* (or, in scientific terms: predictable) growth of forms that are determined by user interaction.

A lot of conceptual hand drawings have been done in order to grasp the optimal construction of evolutionary shapes. Shape, as defined by Arnheim is "…visual material, received by the eyes [that] organizes itself so it can be grasped by the human mind. Only for the sake of extrinsic analysis, however, can shape be separated from what it stands for. Whenever we perceive shape, consciously or unconsciously we take it to represent something, and thereby to be the form of a content." [1]. The generative method that has been used in the experiment has emerged from the extrinsic shape analysis. The analysis has led to the parameterization of shapes that enables interactive adaptation. This parameterization has been one of the most difficult issues in the whole experiment. In order to provide a solution some additional programming of a special module within the generative software was necessary. This module, called ShapeEditor, aimed at maintaining the freedom of creation that is known to artists who sit with a pencil in front of an empty piece of paper. However, when targeting at *adaptive* forms, the art and design practice comes in itself close to programming, even when it involves as conventional activity as linear hand drawing. The freedom of hand drawing applies, in fact, only to shapes that are parts of the sets (of "bodies"), out of which the meaningful forms are being synthesised by genetic algorithms based on user interaction.

Artist and designers don't see what they are creating until the generative software will create the image. But these are artist and designers who determine what the software will create (*figure 2-4*). In the earlier times artists could only dream about such a *systematic creation* [2].

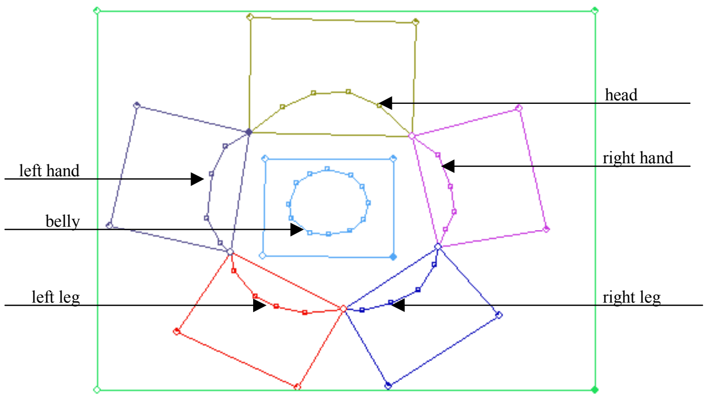

Figure 2: a generic shape grammar of an "embryo" contains a "head", two "hands" and two "legs" in the outline and a "cell" inside, that is in the "belly".

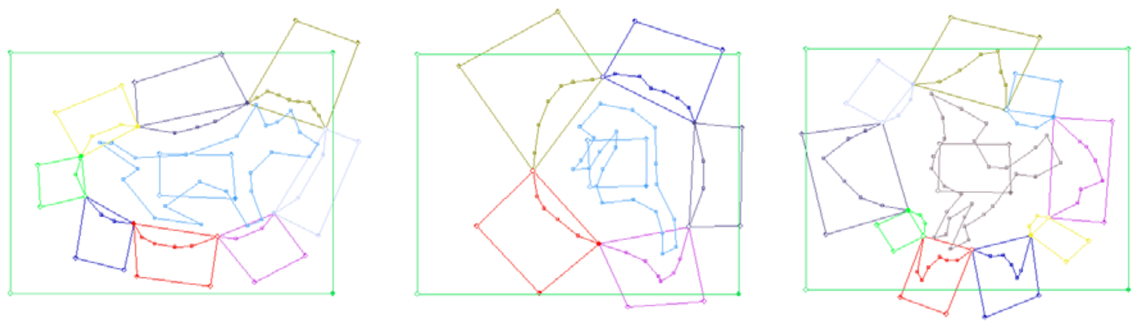

Figure 3: The illustration shows examples of embryos of a "dog", a "seahorse" and a "bird". All forms these are variations of the initial generic form shown in *figure 2*.

Figure 3: The illustration shows a part of the shape grammar set "dogs". The elements of the body have been drawn in the ShapeEditor.

5. Conclusions

In the dialogue between the disciplines, when each discipline works towards its own aims a compromise is often needed. It is rather difficult to distinguish where the input from a discipline starts and where it ends. For example, is the definition of "embryos" art or design or maybe science? But, it is possible to distinguish between values of the outcome for different disciplines involved. Then the interdisciplinary character is better visible.

Design seems to play a good role as a bridge between art and science. Design takes the control over events and questions constantly - *what is it in it for users*. However, this constant design self-reflection makes it actually difficult for designers to switch to generative thinking and accept immediately Generative Art as the possible way of advancing traditional design methods.

In scientific terms Generative Art discipline is maybe not stable enough. But Generative Art gives a practical lesson of the interdisciplinary practice that, although not always measurable, reflects the changes in culture and society.

The domain that certainly benefits form this type of experiments is the domain of art. New tools are emerging that bring fine art back to its roots and into the future in the same time. New tools enable again the classical, but this time software-based analysis of shape and form, and further the analysis of the meaning of shapes and forms and compositions. Even, if those tools are emerging as a side effect of scientific experiments they should be developed further, so that ultimately artists could co-create, for example, some *culture meaning recognition* systems, socially useful tools for multi-cultural information society.

6. Acknowledgments

All illustrations in this paper come from the PAINT generative software developed in Philips Research and are subject to copyright © Koninklijke Philips Electronics N.V. 2001.

It was possible to come to the generative experiment and further to the conclusions about the interdisciplinary value of Generative art thanks to Claudine Conrado, Kees van Overveld and Marcel Tomas, who helped in creating the software and were open for the interdisciplinary discussion.

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Constructing Distributed Fretted Instruments for the Web

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Abstract

In this article, we present a new computer based music instrument for distributed performance on the Web. It was named "Cordas Virtuais" and we took advantage of the recent Java2 implementation to create a general model for fretted-string instruments using class abstractions. There is a heavy usage of JAVA Objected Oriented inheritance to encapsulate gestures derived from fretted string instruments using parameters such as string tuning, group of strings, hand gestures, rhythmic patterns, fingering and alike, that carry each a set of attributes and properties. We call this kind of new musical application as Distributed Musical Instrument (DMI). As an applet, Cordas runs in any browser supporting the current Java Virtual Machine (JVM) across the Web. We describe the concept of PlayStyle that was created to define styles of fingering on the strings. In the implementation we have two class-groups: the left hand and the right hand gestures. The left-hand classes control pitch changes or chords, and a right hand control the rhythm, dynamics, micro-rhythms and rhythmic patterns. A Co-ordination Matrix controls real time changes on left-hand movements. This matrix generates chord orbits that are equivalent to the traditional chord cadences. Finally, to show the potential of Cordas, we presented four musical examples in which a set of fretted instruments varying from the Classical Guitar to the Chinese Pipa were simulated.

Keywords*: **MIDI, Java2, interactive music, fretted instruments, real time***

1. Introduction

Recently, much research has been done to explore the musical potential of the Internet: Burk [1] developed a new Client/Server architecture for multi-user musical performance, (see www. transjam.com). Helmuth [2] discussed several host configurations to allow music performance on the Internet. Complementary, Hwang [3] discussed the concept of "*Virtual Musical Environment*" (VME) where musicians act in a multi-modal feedback process using the Internet. Several new tools to explore the musical potential of the Internet have been developed. Plenty of examples of these systems can be found in (see www.transjam.com/ or http://music.calarts.edu/~tre/JavaMusic.html) the Java Music Projects

Beyond using the Internet as a new musical media, the research presented here is in line with previous works in which "Interactive Music System" (IMS) has been studied. Rowe [4] defined interactive music systems as *those whose behaviour changes in response to music input*. We studied a way of expanding the notion of IMS using generative methodologies. It was started, few years ago, with the definition of Sound Functors [5], a mathematical definition for musical construction and organisation. We explored Evolutionary Computation to created the compositional environment named VOX POPULI [6]. Later, we explore the use of a robot as an interactive actor in a composition system, this was called ROBOSER [7]. Eventually, we also explore the use of new hardware as interface for music performance as presented in [8]. Recently, we participate of the creation of *"ADA: the Inteligent Space"* that used interactive soundscapes to communicate behavioural changes to the audience. This was presented at the EXPO.02 the Swiss National Exhibition for 554.000 visitors. (see www.adaexposition.ch).

This paper presents a research that uses the Internet to expand the concept of IMS. Here we explore the notion of musical interaction creating a new environment that reproduces gestures of a musician when he/she plays a fretted instrument. In our system, class abstractions of a musical gesture are used as input. It can be also used to implement family of fretted instruments which we call *Virtual Strings Instruments* [9]. As an example, it is not difficult to construct a 20-string instrument, each one associated to a different MIDI program and performed by a 7-finger hand or, eventually, to simulate an ancient fretted instrument. As it is discussed later, these features are possible graces in heritage of the class abstraction used in our approach. The recent *Java2* provides interfaces and classes for I/O, sequencing, and synthesis of MIDI data. We used this API to implement fretted instrument characteristics like number of strings and frets, string tunings and the right hand rhythmic actions. *Cordas Virtuais'* classes are easily exchanged among the Web using and musicians can improvise, performing each one a personal string instrument.

In the next sections we present our research in details. We describe the project implementation concepts such as JAVA class abstraction, GUI and play style in the first section. It follows the definition of a simple mathematical model based on a co-ordination matrix to control the left-hand movements. Finally, we discussed the implementation of a set of fretted string instrument as Internet *applet* and this graphical instrument can be used to verify the musical potential of our system.

2. Project Implementation

Our aim was to study how JAVA class implementation can be used in order to create new kinds of sonic interactions. As present in [10], we have been worked with the concept of "*Distributed Music Instruments*" (DMI) to allow musicians to play together and improvise on the Web. In line with [1], we developed a Client/Server architecture where the JAVA based MIDI server imports several MIDI events over the Internet from clients and this allow musicians to Jam on the Web. In this way, this tested interactive architecture allows human and machine to co-operate in distributed musical performance situations.

Additionally, for modeling the musical gesture, we adopted the point of view of a right-hand instrumentalist. The left hand controls the fret choice while the right hand attacks the strings. We used the *tablature* notation to describe the left-hand actions. It allowed a spatial index of a music sequence providing a precise indication of the fret and the string to be played. The right hand movements and rhythm were described by what we called *Play Style*. This is a class abstraction related to the instrument temporal control. Micro-rhythmic structures such as those found on the *Spanish Rasgueado Style* were implemented with success, see www.nics.unicamp.br/cordasvirtuais/. The main classes were divided in *Instrument* and *Performer* packages. *Instrument* contains the Synthesizer, instrument name (MIDI program), number of strings (individual or grouped strings). *Performer* contains representations of the *Tablature* and the *Play Style,* see [10] for details about the classes implementation.

2.1 Strings, Frets and Graphic Interface

Cordas Virtuais is based on a Toolbox developed to enable multi-task MIDI stream control, see Costa & Manzolli [11]. Independent sequences of MIDI data are generated and managed by a *Note Collector* simultaneously.

The *Play Style* interface for micro-rhythmic manipulation (see *Fig. 1*) consists on a interaction area for each string, where the horizontal axis determines the perceptual duration (the moment where the finger touches the string), and the vertical axis represents the attack intensity (finger's velocity)..

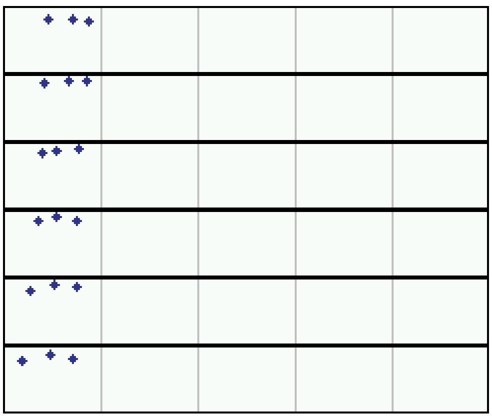


Fig. 1 - *Play Style Interface, vertical lines*

3. Generating Chords Orbits

3.1 Co-ordination Matrix

Def.1: We defined a *Co-ordination Matrix*, denoted as $C_{n \times n}$, a square matrix that is used to control the co-ordination between the left an right hand, n= number of strings group and its entries are defined in the set $\{0,1\}$.

As an example we present below the matrix $C_{6\times 6}$, it was applied in our experiment to generate sequence of chords that can be played in a classical guitar

$$C_{6\times 6} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{31} & C_{32} & C_{33} & C_{34} & C_{35} & C_{36} \\ C_{41} & C_{42} & C_{43} & C_{44} & C_{45} & C_{46} \\ C_{51} & C_{52} & C_{53} & C_{45} & C_{55} & C_{56} \\ C_{61} & C_{62} & C_{63} & C_{46} & C_{56} & C_{66} \end{bmatrix} \qquad \textbf{(1)}$$

where $C_{ij} \in \{0,1\}, 1 \le i, j \le n$, with $n = number\ of\ string\ group = 6$, each group has one string.

Def.2: We define the *Tablature Vector* denoted as $\vec{x}$, an array containing the fret number played on the i^th^ string denoted as $x_i = fret\ number$ $(1 \le i \le n$ with $n = number\ of\ strings)$.

This definition is equivalent to the traditional *tablature* of fretted stringed instruments. Since we are using the classical guitar as references, the order of the frets is: **the highest pitched string (E_4) is related to x_1, and the lowest pitched string (E_2) is related to x_6.**

$$\vec{x} = [x_1\ x_2\ x_3\ x_4\ x_5\ x_6] \qquad \textbf{(2)}$$

with entries $x_i \in \{-1, 0, 1, \ldots, m\}$, where $m = number\ of\ frets$ and it depends upon the instrument we are using, i.e. for classical guitar *m=19*. The entry "-1" is used to mean "*the string is not played*" and it is assigned by the user. The entry "0" is used to mean an *"opened string"*.

Def.3: Given an initial *Tablature Vector* $\vec{x}_0$ and a *Co-ordination Matrix* $C_{6\times 6}$ we call $\vec{x}_{K+1}$ the next *Tablature Vector* in a sequence $\{\vec{x}_0, \vec{x}_1, \vec{x}_2, \ldots, \vec{x}_n\}$. This sequence is called here as *Chord Orbit* or *Cadence,* and it is generated by the matrix product and a *mod* operation, as defined below:

$$\vec{x}_{K+1} = C \cdot \vec{x}_K \qquad \textbf{(3)}$$

where $\vec{x}_K$ is the k^{nd} *Tablature Vector* and $C_{6\times6}$ is the *Co-ordination Matrix*.

In order to confine the entries of the $\vec{x}_{k+1}$ in the set $\{0, 1, \ldots, m\}$ we apply at it *k-step* the following operation:

$$\vec{x}_{K+1} = [x_1 \bmod m, x_2 \bmod m, \ldots, x_n \bmod m] \quad \textbf{(4)}$$

where *mod* operation gives the Z_m correspondent for each entry.
As an example of a cadence defined for a Classical Guiter and generated by the *Co-ordination Matrix*, we introduce an initial *Tablature Vector* related to a **G**^{7} chord $\vec{x}_0 = [1\ 0\ 0\ 0\ 2\ 3]^T$. The *Co-ordination Matrix* that generates the next chord **C/G**, $\vec{x}_1 = [0\ 1\ 0\ 2\ 3\ 3]^T$ is presented below:

$$\vec{x}_1 = C \cdot \vec{x}_0 = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 2 \\ 3 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 2 \\ 3 \\ 3 \end{bmatrix} \quad \textbf{(5)}$$

Def. 4: Given a *Tablature Vector* $\vec{x} = [x_1\ x_2\ x_3\ \ldots\ x_n]$ where $n = number\ of\ strings$, the MIDI note number table defined in $[0 \ldots 127]$ and a string tuning note number T_i with $1 \le i \le n$ for each string, the note number y_i played by *Cordas Virtuais* is defined as:

$$y_i = T_i + x_i\,, 1 \le i \le n \quad \textbf{(6)}$$

where $x_i \in \{0,1,\ldots,m\}$ and it is generated by equation **(3)** or the entry -1 is assigned by the user.

Using **Tab 1.0**, it is possible to calculate the MIDI note number played by the system. Given the *Tablature* presented in **(4)**, the result is:

$$\mathbf{G^7} = [1\ 0\ 0\ 0\ 2\ 3]^T + [64\ 59\ 55\ 50\ 45\ 40]^T = [65\ 59\ 55\ 50\ 47\ 43]^T \quad \textbf{(7)}$$

$$\mathbf{C/G} = [0\ 1\ 0\ 2\ 3\ 3]^T + [64\ 59\ 55\ 50\ 45\ 40]^T = [64\ 60\ 55\ 52\ 48\ 43]^T \quad \textbf{(8)}$$

Classical Guitar Tuning Table						
string	1st	2nd	3rd	4th	5th	6th
pitch	E3	B2	G2	D2	A1	E1
MIDI Number	64	59	55	50	45	40

Tab 1.0 *Tuning system of the classical guitar. The first row is the string order, the second row contains the tuning for each string and the third row is the MIDI note number. These entries are equivalent to* T_i*, with* $1 \le i \le 6$.

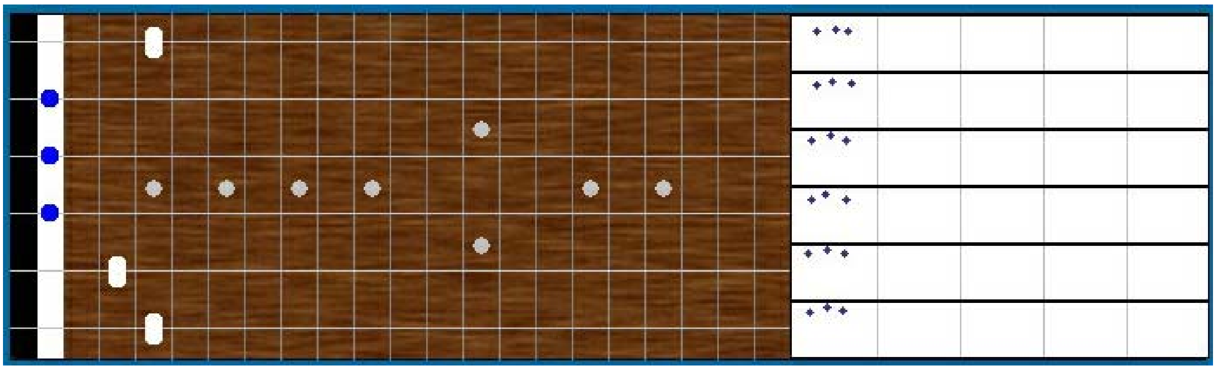


Fig. 3 – Cordas GUI Interface for a *Classical Guitar. In the left side, the white dots indicate pressed fret positions. |In the right side, dynamics, micro-rhythms and rhythmic patterns are described by blue dot positions.*

4. Instrument Case Studies

As mentioned above, the Classical Guitar was the first instrument studied, but the *Cordas Virtuais*'s objected oriented structure allowed an easy creation of new instrument instances. This section presents three applets implemented using Cordas, they are the Chinese *Pipa*, Andino *Charango* and the African *Kora*. The follow information are needed: a) Tuning Table and MIDI program number as seen on **Tab 1.0**, b) Number of string groups and c) Number of strings per group. The implementation of the *Kora* applet required to use to playstyle interfaces, since there is no fret use in this instrument and both hands are used to stroke the strings (like a harp). So, it was decided to use two *PlayStyle* pads, one in the right side and other in the left side (see

4.1 Pipa

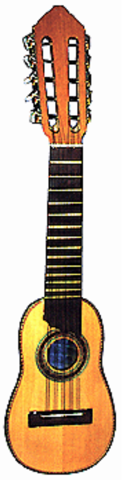
Fig. 4 – The Chinese Pipa with four strings

It is a four-stringed Guitar like instrument, one of the oldest Chinese musical instruments created in China more than 2000 years ago. The instrument later was developed from its orginal two strings design into a form of four strings and twelve frets, plucked with fingernails and known as pipa or qin-pipa. Pipa was a general term referring to those plucked-string instruments played in hand-held positions with the outward fingering technique called "pi" and the inward one called "pa".

Pipa Tuning Table			
1st string	2nd string	3rd string	4th string
A4	D3	E3	A3
81	76	74	69

Tab 2.0 - *Tuning system of the Chinese Pipa.*

4.2 Charango



It is the main stringed instrument used in Andean music, The resonance box is usually made from an Armadillo shell or carved wood imitating the shell. It is used in almost traditional music of Peru and Bolivia.

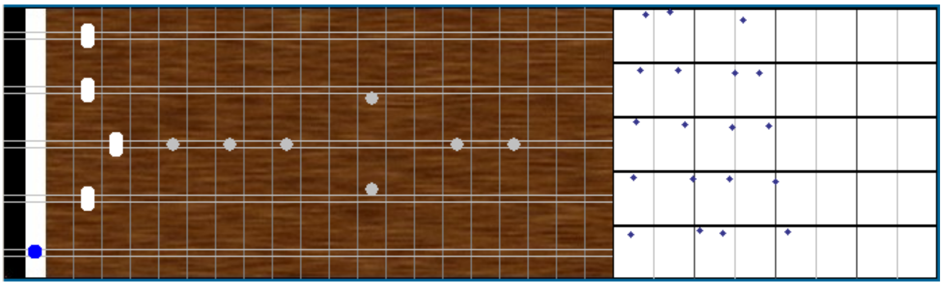


Fig. 5 – In the left, the Andean Charango with 5 group of double strings. Above, the GUI of Charango applet where one can see the double strings on the left side.

Charango Tuning Table				
1st double string	2nd double string	3rd octave string	4th double string	5th double string
E5,E5	A4, A4	E4, E5	C4,C4	G3, G3
88,88	81,81	76,88	72,72	67,67

Tab 3.0 – Tuning system of the Andean Charango

4.2 Kora

Fig. 6 – The African Kora

The Kora is arguably the most complex chordophone of Africa. It is played in the westernmost part of Africa in Mali, Gambia, Burkina Faso, Guinea, Sierra Leone, and Senegal. The calabash is covered with a cowhide that is stretched over the open side of the half calabash and then left in the sun to dry tight and hold the handposts in place. A Traditional Kora has 21 strings and it is not a fretted instrument, actually Kora is played with two hands simultaneously. Despite, it is not an instrument we decided to implement a new applet using two Play Style pads, one for each hand. The left pad has 10 strings and the right has 11.

Kora Left Hand Tuning Table										
B4	G4	E4	C4	A3	F3	D3	B2	A2	G2	C2
83	79	76	72	69	65	62	59	57	55	48

Tab 4.0 – The tuning system of the Kora´s Left Hand

Kora Right Hand Tuning Table									
E5	D5	C5	A4	F4	D4	B3	G3	E3	C3
88	86	84	81	77	74	71	67	64	60

Tab 5.0 - The tuning system of the Kora´s Right Hand

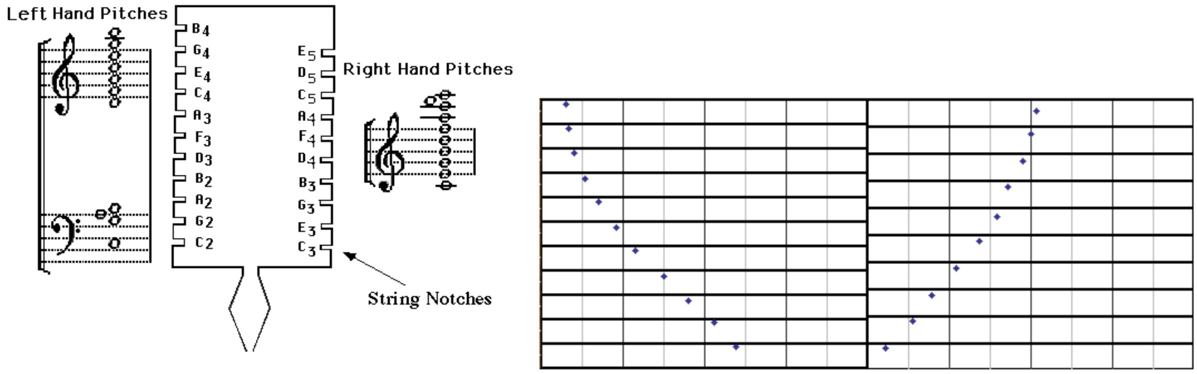


Fig. 3 – *(left) Kora Tunning system, (right)* Cordas Virtuais *Interface for Kora*

5. Discussion and Feather Developments

We presented examples of four fretted string applets: the Classical guitar, the Chinese pipa, the Andean Charango and the African Kora. These applets can be found in official Cordas Home Page (www.nics.unicamp.br/cordasvirtuais). The instrument case studies presented above showed the potential of the software and its flexibility resulting of the usage of class abstraction and inheritance. The mathematical model used to define the Co-ordination Matrix, is simple enough to be explored a dynamic system. The patterns on the Matrix can be controlled by several generative algorithms. Particularly, we intend to apply evolutionary computation as we have been studied in previous works [6]. One of the most interesting features of *Cordas* is that users can be seen as musician performing a jam section each one using a different instrument applet. We have tested this situation using a Client/Server architecture we developed [10,11], the result was really an interesting sound on the MIDI server. It produced a complex interweaving of melodic lines such as a Internet chat situation in which a group users write messages in different languages and the screen presents a multi-linguistic discourse.

The next steps of this research will be:

1) To study mathematical transformation on the co-ordination matrix in order to identify and control patterns as well generative structures;
2) To create an application version of Cordas improving several musical and control parameters parameters of the GUI, such as Load, Save PlayStyle, Save MIDI File, Record Pattern;
3) To integrate Cordas with other compositional environment we have developed at NICS, such as Roboser, VoxPopuli, etc.

Cordas will be applied to provide the exchange of fretted instrument features and performance characteristics distributed on the web. A database of *tablature* and *Play Style* will be constructed in near future.

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Exploring Aesthetic Pattern Formation

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Abstract

This paper is an exploration of an interdisciplinary nature. Through studies in fine art, pattern formation in nature, and artificial life, a mechanism for the artistic process is presented. Asynchronous updating schemes implemented in cellular automata and pheromonal agent swarms were evolved to produce aesthetic patterns and compared favourably to non-evolved synchronous production methods. The curious adaptive properties of the resulting patterns were investigated.

1. Introduction

"When we stand before great churches, temples, pyramids, and other works of architecture built hundreds, if not thousands of years ago, our minds are filled with awe and admiration. Yet there have been architects millions of years before that. Their work, it is true, owes its existence not to the inspired genius of great artists, but to the unconscious, unremitting activity of the force of life itself." [1] Pp 2.

There remains a great deal of mystery surrounding the processes involved in the generation of aesthetic and functional forms, as they occur in nature and as generated by humans. Many would still like to believe that both human and natural generation of aesthetic form, at some level at least, a conscious creative plan, some central idea, meaning or goal. Artificial life offers an alternative paradigm of thought, and it is the point of this paper to explore how the seemingly disparate domains of pattern formation, social insect communication and artistic processes can be linked.

The aim of this paper is to show that the processes involved in the formation and generation of shapes and patterns, aesthetic or functional, are best viewed as evolved adaptive systems. Formation relies on distributed local rules and sensorimotor interactions rather than any global ideals or representations. There is reasonable evidence to suggest that asynchronous updating in adaptive systems is more biologically plausible [2][3], and it will be shown that this can also be considered the case for human artistic 'updating' of paintings.

The following section contains a brief overview of background material. An analysis of the processes involved in the production of my own artistic works was carried out and is detailed in section 3. Section 4 outlines the Cellular Automata model, the Pheromonal Agent System and the Genetic Algorithm implemented. The adaptive properties of the resulting patterns were investigated and three such experiments with their results are detailed in section 5. Section 6 contains conclusions drawn from this work.

2. Background

There are many areas of nature where ordered patterns occur. It is interesting to note that the idea of formation as a result of *local interactive signals producing adaptations in movement* can be used as a model of growth of patterns in both animate and inanimate forms, for example snowflakes, animalcules, nests and mammalian coat patterns [1].

Pattern formation is concerned with how the spatial arrangement of cells occurs. It would appear that pattern is generally laid down early on providing good evidence for the autonomy of development as a separate process [4]. However, there is as yet no experimental evidence to support any of the proposed pattern formation theories offered by theoretical biology.

Pattern formation was originally dominated by theories in terms of *prepatterns*, the idea that developmental fields have a non-uniform spatial arrangement of substances in a tissue whose local peaks induce the formation of pattern elements, i.e. pattern is preprogrammed, laid out globally [5]. *Positional information* was an alternative approach that replaced this outdated theory and paved the way for a number of interesting theories all incorporating local cell to cell interactions as a method for pattern formation, rather than a predefined arrangement of pattern elements [4][5].

Cellular Automata have been used to model pattern formation as it occurs in many domains e.g. mammalian coat patterns, seashell patterns and embryological pattern formation. This is mainly because of the general property of local interactions to produce global phenomenon, meaning that they provide a good generic model of other models of pattern formation, for example the Turing system [6].

There are many species that construct complex architectures, social insects can be seen to generate hugely intricate patterns and structures when nest building, the possible organisational mechanism put forward in [7] to explain how this can occur is *stigmergy,* a form of self organisation. The basic idea is that the coordination of individuals' tasks depends not on any communication between them but on the nest structure itself [6]. A termite picks up a soil pellet, impregnates it with a 'cement pheromone', which diffuses away, attracting other termites to drop their pellets near by.

Aesthetic evolution selection by a human observer has been much utilised for the generation of, often stunning, visual images, [9][10][11]. However, as pointed out by Dorin [11] the images evolved not only reflect the users desires but more importantly the restrictions of the program. Dorin notes that the user selection process is a top down method for generation of form, in a 'choose your own adventure book' way, that is, no matter how creative the user tries to be, the image cannot stray out of the ones available in the book. This 'explorer' rather than 'artist' generative method seems far removed from the bottom up procedures implemented in my own art. The process of globally assessing the aesthetic merit of an image should not be confused with the local updating of a canvas with aesthetic intention; art appreciation is not synonymous with art production.

Design by distributed systems reflects the processes observed within many fields and also the current trend to explore the computational possibilities for exploiting design theories, such as computer aided design packages for Architecture, robot morphologies and furniture design [6][12][13]. Computer simulations have been put forward as works of art themselves, artist Paul Brown used cellular automata to produce very attractive and distinct images, however, they were aesthetically biased by the use of patterned tiles and randomness rather than relying only on the cellular Automata rules[1].

3. The Artistic Process

Generally, in work done using distributed models of pattern and structure formation in nature the method is contrasted with the centralised, plan based methods assumed to be invoked by humans, particularly artists and architects [1]. This assumption is just as short sighted as the prepattern approach was to pattern formation and it is hoped that highlighting this in this paper could spark further, more realistic models of aesthetic production that are all encompassing, as positional information did for pattern formation.

There are certain principles, techniques and medium specific methodologies that contribute to the attractiveness and quality of a piece of painting. Artistic talent is far from a magic, indefinable essence, possessed by the few and jinxed by deconstruction. Rather it can be thought of as the conscious or unwitting implementation of an adaptive system, consisting of a particular updating scheme and low level local rules or techniques, which have been arrived at through an evolutionary process.

“I first thought that making a portrait consisted of looking at the model and drawing the portrait, and that this entailed artistic creativity and was quite a mysterious process.” [14] Pp 24.

Using eye tracker tests, which record precisely where the eye was looking and motion trackers which tracked the movements of the hands in space, Tchalenko et al tried to find out what the ‘magical’ process involved in the drawing of a portrait is. Their results back up my own experience and method of portrait painting. To begin with the painter makes very quick precise eye movements on the paper and the sitter followed by very small markings on the paper. As the picture progresses longer and longer periods are spent looking at larger and larger sections of the paper, and not the sitter, and producing bigger bolder sweeping movements. Tchalenko concluded from these observations that “portrait painting, at least for this painter, was a complex combination of a fading memory image and an increasing presence of the emerging picture” [14] Pp 24.

It is crucial to the development of the picture how each local area to be assessed and altered is selected. This is based on the idea that the *global* image is not assessed at each paint stroke and that the small area viewed is important to the type of stroke made. It is clear, from the fact that there is generally only one hand making any movements on the canvas at any one time, that the updating of each section of the painting can not happen at once, the areas of the painting are updated *asynchronously*.

There are many different methodologies employed for the development of a picture. For example, it is not generally advised to make one tiny area of the painting perfect and polished before painting any other areas. Interestingly enough this discouraged method is the most prolific among untrained artists and school age children. A more refined approach, which is medium specific, is to move about the painting in a systematic or random way (but generally hitting every area of the canvas) and, for example with oils and acrylics only put down dark

[1] Insight from Paul Brown at Blip sci-art discussion group Brighton 22/07/02

paint where it is needed and then move on. Only once an area is encountered that needs no more dark are the next lightest shades applied, this process continues until the white highlights are added, then, in theory, the painting is finished. This was the updating scheme used in fig 1.

Figure 1: *Adaptive Cubist* K A Bentley 2002

There are some general rules that are taught and can be observed in aesthetic works. For example the rule of complementary colours and that shade supports light, that is, light should always be next to dark [15][16]. It is not suggested that all aesthetic pieces are, or can all be, produced using the *same* rules but just that an interactive rule based system can be a good generic model of aesthetic production.

All established artists have a distinct style. They will have experimented with and learnt from other styles and it is through the discovery of new rules and the effect of the interaction of that new rule with others that arts creativity and novelty perpetuates. As with evolutionary models, children's paintings are in general not aesthetically pleasing, they are the beginning of a very long learning and refining process, picking out the good tricks and the bad ones and repeating pleasing structures but within new environments and with different rules. This process has also been noted in the drawings of apes [17]. Recurrent themes and paint application techniques along with updating schemes and implementation of particular aesthetic rule systems like those already described can define an artist's unique style [15].

4. The Models

To investigate the aesthetic potential of the evolutionary, adaptive methodology put forward in this paper, two self-organising systems were experimented with. Cellular Automata (CA) and Pheromonal Agent Systems (PAS) were used because of their ability to model other adaptive distributed systems and due to their connection with natural pattern and structure formation models.

The Genetic Algorithms (GA) employed for the evolution of the CA and PAS were of the same generic structure. However it became necessary to alter the various parameters given the different situations as it became clear that the updating systems greatly affected the size of the search space, given that asynchronous updating meant that the same rule set genotype could map to several, albeit similar, phenotypes. It was not known if there would be patterns that could form independently of this random updating and even if they could cope with the asynchronous nature of updating within the CA or PAS, although the results obtained in the preliminary experiments suggested that there would [18].

4.1 Cellular Automata

A two dimensional ($M \times N$) toroidal CA was used. Each cell p represented the pixel in the (m, n) co ordinate position, where $m \in M$, $n \in N$. Each cell could be in one of four states representing four colours. In most experiments the radius r of the CA, specifying the range of the update rule, was 1. In all experiments the initial CA cells were randomly set.

Three types of updating were investigated: *synchronous* (Synch), *asynchronous set* (Asynch Set) and *asynchronous random* (Asynch Rand). Asynch set updating meant that at each stage only one cell was updated, and that cell was set. The first cell to be updated was cell (0,0) then cell (0,1), then (0,2) all the way through the rows and columns in order. A time step corresponded to one complete run through all the cells being updated. Although this is asynchronous it is still a deterministic form of updating. In Asynch Rand updating one cell was picked at random to be updated at each stage, with replacement. Unlike Asynch Set updating, after $M \times N$ stages not all cells had necessarily been updated. This was a non-deterministic form of updating. One time step corresponded to $M \times N$ updating stages. So for all types of updating, in a time step, on average, all cells would have been updated.

4.2 CA Genotypes

The CA genotypes were split into eight blocks, one for each rule. The position of a block in the genotype was crucial as the first two were the rules to implement if the pixel was of the first colour, the next two blocks if it was the second colour and so on, for each of the four colours. Each block contained four genes. The first gene in a block chose the counter to assess, the second related to the operation to use in the rule. Five operations were possible, =, <, >, ≥, ≤. The third gene was the condition, and the fourth was the action. There was a probability of 0.5 that no action would be taken.

For example if the four genes of the first block were 1,2,3,2 then the rule would expand to be: if p=0 and $C1 > 3$, then $p \rightarrow 2$. Where $C1$ denotes the number of neighbours whose state = 1. The rules expanded in a hierarchical format. This resulted in a lot of the genotype essentially being *junk DNA*, as earlier rules took priority.

4.3 Pheromonal Agent System

The PAS was an extension to the Basic Agent Model that was experimented with in [18]. Agents were placed in N randomly chosen, with replacement, cells of the CA array. $r = 1$ which might or might not have been inclusive of the agents cell. The agents all updated the particular cells they ‘inhabited’ synchronously by assessing the states of the cells in the given radius, they then moved to one of their eight neighbouring cells. Each agent was capable of leaving and reacting to plumes of a ‘pheromone’ that diffused over time. The movement of agents was governed either by pheromone reaction rules or neighbour states or a hierarchical combination of both. The CA cells initial states, in all experiments, were set to 0.

The pheromone diffusion was based on random walk diffusion [19]. After a pheromone plume was dropped at cell (m,n), the amount of pheromone A at any given cell in the array, of Euclidean distance x from (m,n) at time t from when the plume was dropped was given by equation (1) where D is the diffusivity constant (how much the chemical diffuses at each time step) and Q is the amount of pheromone dropped.

$$A = \frac{Qe^{-x^2/4Dt}}{2\sqrt{\pi Dt}} \tag{1}$$

4.4 PAS Genotypes

The PAS genotypes were split into eight blocks with six genes each. Unlike the CA GA the state of the cell that the agent inhabited was not assessed. However the position of a block was just as important as a hierarchical rule system was again implemented. The first four of the six genes related to the same rule specifications as in the CA genotypes, the fifth specified whether to move to or away from pheromone detected and the sixth specified whether a plume of pheromone was to be dropped or not. Thus the movement system was simple, but was enough to create complexity in the resulting image. The PAS genotypes then had an extra four genes that specified Q, D, t and the optimum number of agents (*AGENTS*). Unfortunately, due to the effect large numbers of agents and plume diffusion time had on evolutionary run time a limit of 20 for each had to be enforced, this was found to be small enough to allow a pattern to develop and run time to be realistic.

4.5 Evolution

A population of 100 genotypes were evolved for 100 generations. The system was elitist. The top scoring genotype would be replaced into the next population. The top 10 fittest genotypes would become the parents of the next generation, and from this parent pool random parents, with replacement, were chosen to be crossed over at some random starting point of a rule block in their gene string. The resulting genes were then subject to mutation. Each one had a probability of 0.05 of being mutated, so on average 1.6 genes were mutated.

5. Experiments and Results

In this section two of the evolved asynchronous CA patterns generated and one PAS pattern will be analysed. For details of other experiments and patterns obtained see [18].

Fig 2 shows some of the images that were attained without the use of evolution. Various rule sets were experimented with, *smudged ink* shows the effect of involving variable paint trail width into the rule sets. *Game of Life* is simply an Asynch Set updated version of Conway's game of life rules [20]. *Reticulation* was a style of pattern that occurred within many of the arrangements of rule sets, as well as being highly prolific in nature [18], the piece shown in fig 2 is an enhanced section of the *game of life* when updated with Asynch Rand. Without evolution it was highly time consuming to create aesthetically pleasing rule sets, and the act of doing so began to resemble the evolutionary process described in section 3.

For all evolutionary CA experiments a grid size of 40 × 40 was used and for the PAS 30 × 30 was used. This is because it was necessary to minimise run time whilst retaining complexity in the patterns.

5.1 Fitness Function

As it was not the intention to obtain a specific global image but for the pattern to self organise into an aesthetic state local fitness functions were experimented with, with the general aim of achieving mosaic like or clustered patterns.

The fitness function was of the following general form, where there are *n* conditions (*RC*) that must be satisfied to be rewarded and *m* conditions (PC) that if satisfied, the function is penalised and reset to 0. The amount of the sixteen neighbours, outside of $r = 1$ but within $r = 2$, of a certain state *s* will be denoted by *R2Cs*. *One, two* and *three* refer to the number of cells in the entire CA grid that are of the respective state. See equation (2).

$$fitness = \begin{cases} 0 & if\ \ PC1\ is\ true \\ \vdots & \\ 0 & if\ \ PCm\ is\ true \\ \sum_{p=0}^{N\times M} f(p) & otherwise \end{cases} \qquad f(p) = \begin{cases} 1 & if\ \ RC1\ is\ true \\ \vdots & \\ 1 & if\ \ RCn\ is\ true \\ 0 & otherwise \end{cases} \tag{2}$$

Every member of the population was subjected to 5 trials to eliminate patterns that were dependent on the initial conditions. The fitness was judged on each of these trials and the total score for a genotype was the sum of these. In general the fitness was judged at the 40th time step allowing the pattern to develop into its stable state. For Asynch Rand updating 100 steps for development were used, also functions for agents that didn't reward for *C0* surrounds, i.e. the canvas colour, also needed around 100 time steps for the canvas to be covered in other colours in development.

The occurrence of blanket grid, where all cells were the same colour, became an issue when evolving both the CA rules and the PAS rules. This was due to certain fitness functions, originally designed to reward for clustering, actually being optimised by a blanket grid. This was an uninteresting state for the CA to be in, thus every experiment had a harsh penalty (fitness set to zero) if, at the time step where fitness was evaluated, a blanket grid was detected. However, one problem was that the rule set may be on course to converge to a blanket, but *after* the evaluation time step, meaning that it optimised the fitness function, avoided the penalty *and* remained an uninteresting pattern. Harsher penalties ensued, where fitness would be set to zero if more than half the cells were of the same colour, with this, it was rarely seen, but blankets, with extra long times before convergence, still sneaked in.

5.2 Evolved Asynch Set CA Pattern: *Red Tiles*

The pattern evolved with the fitness function in fig 4 is shown in fig 3 and tentatively titled *Red Tiles*. The fitness function used was a competitive one, meaning that if one pixel satisfied the function then its eight neighbours necessarily could not. It was also a forgiving fitness function in that the fitness for a pattern would accumulate as more of the pixels satisfied it, rather than being dependent on a specific outcome globally. This forgiving fitness was found to be necessary when the desired outcome required that the radius 2 neighbours be of a specific colour as no patterns early on in evolution would be able to satisfy this outright. The desired image was a mosaic like tile pattern where tiles would comprise of a central colour and two outer rings of different colours. What emerged were tiles with only one, red, outer ring floating in a sea of another colour. This is due to the forgiving nature of the fitness function.

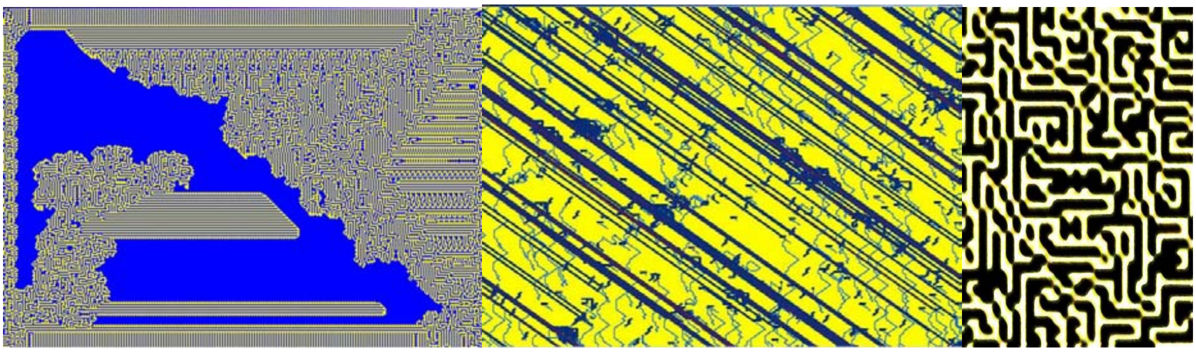

Figure 2: From left to right: Asynch Set CA *Game of Life* [25], PAS *Smudged Ink,* Aysnch Rand CA *Reticulation.*

Adaptation to Perturbations:

Fig 5 show that *Red Tiles* was able to adapt to perturbations in the states of a randomly chosen, random amount, of its cells, although the original high fitness was never fully recovered. The oscillatory nature of the steady periods reflects the presence of cyclic attractors in the developed pattern. Fig 5 also shows the effect of using one of the other updating environments on the fitness of this pattern. With Asynch Rand updating it climbed slowly to reach a similarly high fitness but with synch updating it was unable to reach even half the desired fitness. This highlights the importance of ascertaining the correct updating environment to evolve within and the huge difference that updating schemes can make to the formation of a pattern.

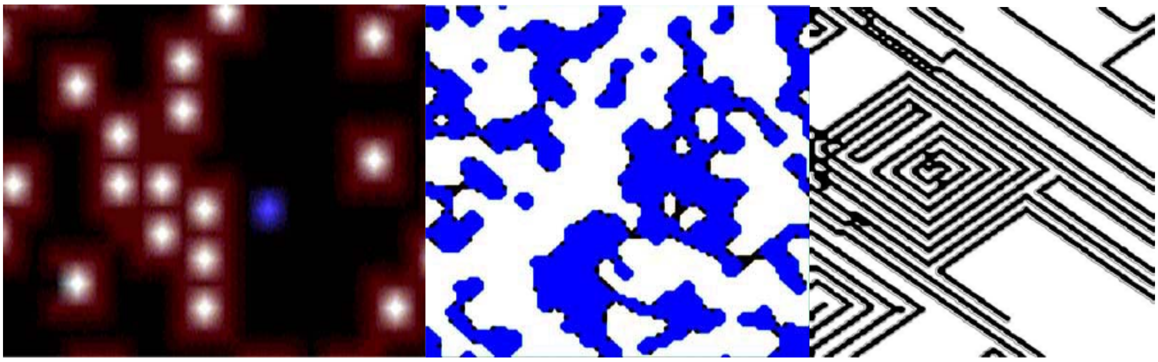

Figure 3: From left to right: Sections from evolved Asynch Set CA *Red Tiles,* Asynch Rand CA *Camouflage,* PAS pattern *Spirals.*

Fitness Function:

RC1: if $C0 = 8$ & $p = 2 \Rightarrow f(p) = 1 + \text{R2C1}$
RC2: if $\text{C1} = 8$ & $p = 3 \Rightarrow f(p) = 1 + \text{R2C2}$
RC3: if $\text{C}2 = 8$ & $p = 0 \Rightarrow f(p) = 1 + \text{R2C3}$
RC4: if $\text{C3} = 8$ & $p = 1 \Rightarrow f(p) = 1 + \text{R2C0}$
PC1: if zero or one or two or three $\geq (\text{N} \times \text{M}) - 30$

Rules Evolved:

if $p = 0$ & $C0 \geq 1 \Rightarrow p = 2$
if $p = 0$ & $C3 > 2 \Rightarrow p = 1$
if $p = 1$ & $C3 < 7 \Rightarrow p = 2$
if $p = 1$ & $C2 < 4 \Rightarrow p = 1$
if $p = 2$ & $C0 < 1 \Rightarrow p = 3$
if $p = 2$ & $C3 \leq 5 \Rightarrow p = p$
if $p = 3$ & $C3 < 3 \Rightarrow p = 2$
if $p = 3$ & $C0 = 2 \Rightarrow p = 0$

Figure 4: Fitness function and Rules for evolved Asynch Set CA *Red Tiles*

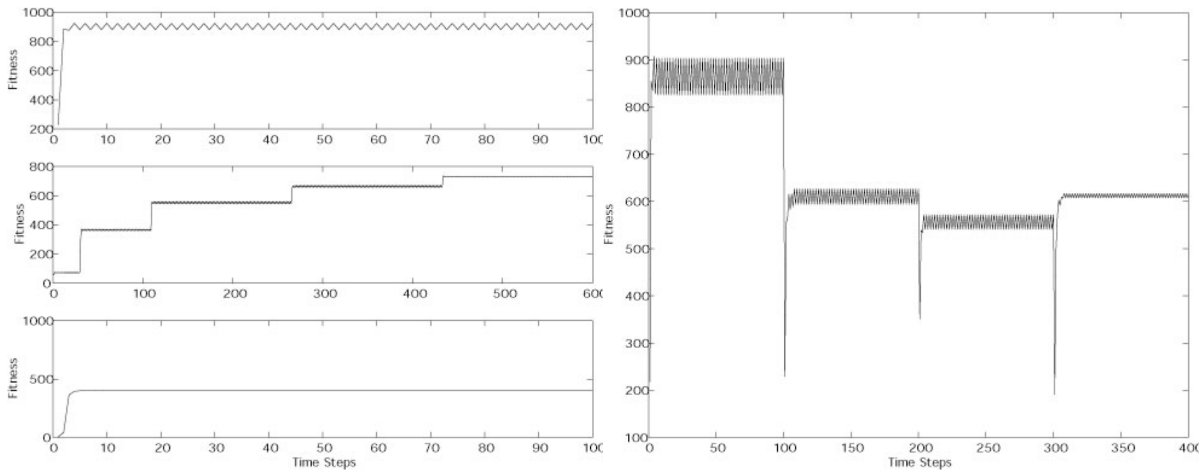

Figure 5: Left: graph showing the evolved Asynch Set CA *Red Tiles* when updated with (top to bottom) Asynch Set, Asynch Rand and Synch. Right: graph showing *Red Tiles'* ability to adapt to perturbations occurring at time steps 100, 200 and 300.

5.3 Evolved Asynch Rand CA Pattern: *Camouflage*

In order to evolve a pattern that didn't cheat the restrictions on blanket formation, by only developing into a blanket once the time step where fitness was judged, a tougher penalty was enforced. This did not completely rule out blanket formation, but it did mean it was considerably less likely. The desired outcome was clustering, that pixels of the same colour would cluster and be surrounded by a different colour. The resulting pattern, shown in fig 3, from the fitness function in fig 6 exhibited pseudo periodic behaviour such as that described in [2]. Shapes resembling army camouflage patterns formed with flickering boundary cells.

Fitness Function:
RC1: if $C0 = 8$ & $p = 0 \Rightarrow f(p) = 1 + \text{R2C1}$
RC2: if $C1 = 8$ & $p = 1 \Rightarrow f(p) = 1 + \text{R2C2}$
RC3: if $C2 = 8$ & $p = 2 \Rightarrow f(p) = 1 + \text{R2C3}$
RC4: if $C3 = 8$ & $p = 3 \Rightarrow f(p) = 1 + \text{R2C0}$
PC1: if zero or one or two or three $\geq (N \times M) \times 0.5$

Rules Evolved:
$p = 0$ & $C1 > 3 \Rightarrow p = 3$
$p = 0$ & $C0 = 3 \Rightarrow p = p$
$p = 1$ & $C2 < 0 \Rightarrow p = 0$
$p = 1$ & $C1 < 4 \Rightarrow p = 3$
$p = 2$ & $C0 \leq 2 \Rightarrow p = 1$
$p = 2$ & $C0 > 3 \Rightarrow p = 0$
$p = 3$ & $C2 < 6 \Rightarrow p = 2$
$p = 3$ & $C2 \geq 1 \Rightarrow p = 3$

Figure 6: Fitness function and rules for evolved Asynch Rand CA pattern *Camouflage*

Adaptation to Perturbations:

The graphs in fig 7 show that this pattern was highly successful at retaining its fitness in the face of perturbations in cell state and in updating scheme.

5.4 Evolved PAS Design: *Spirals*

Using a fitness function, shown in fig 8, that rewarded for a pixel to be partially surrounded by a specific colour other than that of the pixels, led to an interesting spiral pattern. The surrounding was partial because the agent system couldn't cope with the stricter full surrounding version. No RC was set for the surrounding to be partially *C0* as the agents CA began with a blanket 0 setting. The second PC was introduced in this case so that pheromone

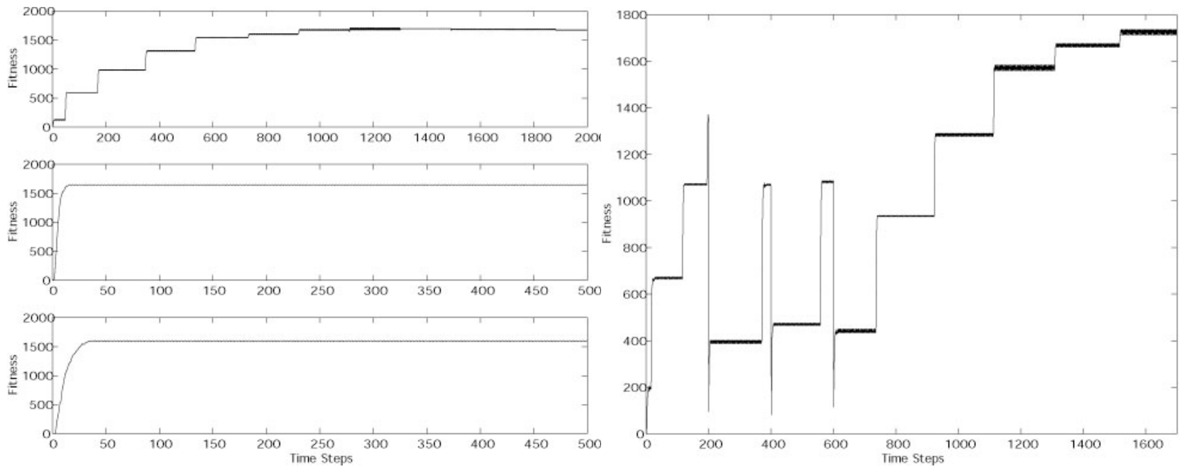

Figure 7: Left: graph showing the evolved Asynch Rand CA *Camouflage* when updated with (top to bottom) Asynch Rand, Asynch Set and Synch. Right: graph showing *Camouflages'* ability to adapt to perturbations, occurring at time steps 200, 400 and 600.

was definitely going to be used by the agents. When analysed the rules were particularly curious in their simplicity. The agents were only ever implementing one rule. The second rule, 'if C0 was less than or equal to eight', which of course it always was, occurred above any other rules meaning that, through the hierarchy system, the others were made obsolete. Essentially the agents were always leaving pheromone and always moving away from it. What emerged from this very simple set up was a spiraling pattern, interestingly similar to the aggregate spirals of social amoebae especially as it seems to be the opposite signaling system to that currently proposed [18]. Fig 9 shows the development of the pattern and an enhanced section of this image is shown in fig 3.

Fitness Function:
RC1: if $C1 \geq 5$ & $p \neq 1 \Rightarrow f(p) = 1$
RC2: if $C2 \geq 5$ & $p \neq 2 \Rightarrow f(p) = 1$
RC3: if $C3 \geq 5$ & $p \neq 3 \Rightarrow f(p) = 1$
PC1: if zero or one or two or three $\geq (N \times M) - 30$
PC2: if TIME = 0

Rules Evolved:
$C1 \geq 2 \Rightarrow p = p$, move away from pheromone, leave plume
$C0 \leq 8 \Rightarrow p = 3$, move away from pheromone, leave plume
$C3 = 0 \Rightarrow p = 2$, move away from pheromone
$C0 > 7 \Rightarrow p = p$, move towards pheromone, leave plume
$C2 = 2 \Rightarrow p = 1$, move away from pheromone, leave plume
$C2 > 0 \Rightarrow p = p$, move away from pheromone
$C3 \leq 4 \Rightarrow p = p$, move towards pheromone
$C0 > 4 \Rightarrow p = p$, move away from pheromone, leave plume
AGENTS = 18
t = 11
Q = 7.408590
D = 3.661763

Figure 8: Fitness function and rules for evolved PAS pattern *Spirals*

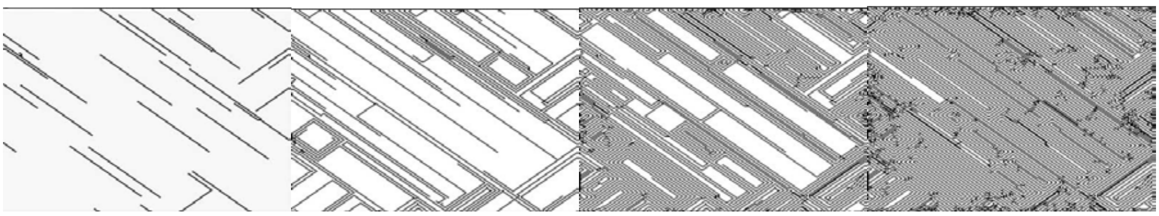

Fig 9: Development of Pheromonal Agent Design *Spirals*

Adaptation to Perturbations:

As the PAS was evolved with the initial CA as a 0 blanket, perturbing the state of cells within the range of *all* possible colours meant that the spiral design was irredeemable, see fig10. However changing a random amount of cells back to 0, i.e. ‘rubbing out’ some of the design didn’t stop the rules recovering to a high fitness, although the characteristic spiral pattern reverted to a reticulation design.

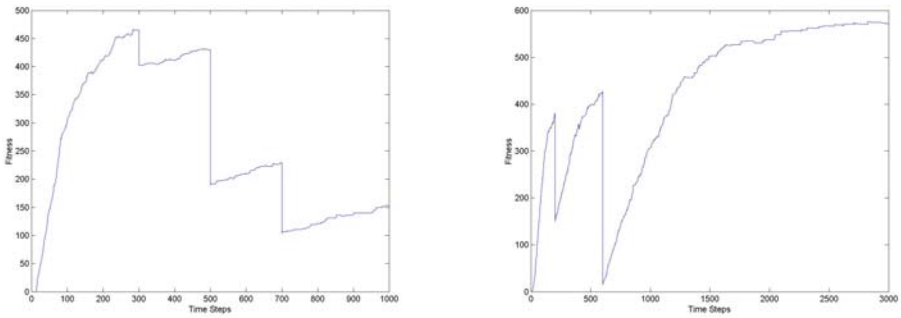

Figure 10: From left to right: Graph showing the evolved PAS *Spirals* lack of adaptation to perturbations at time steps 300, 500, 700. Graph showing the evolved PAS *Spirals* adaptation to ‘rubbing out’.

6 Conclusions

Inspiring insights can come from interdisciplinary research. This project has confirmed the hypothesis that the evolution of asynchronously updated systems (CA or PAS), in particular Asynch Rand updating, is a good generic method for the production of adaptive aesthetic patterns and images, in agreement with observations made of the artistic process and observations in nature.

Through this project it is clear that evolution *can* find robust solutions to form patterns in the face of random initial conditions, a random updating scheme and random perturbations as long as the population are exposed to this throughout the evolution.

The choice of time step for testing the fitness of the patterns played a crucial role in the type of pattern that formed. If the fitness was judged too early then the pattern could still dissolve away into a blanket state, and if it was too late then it rewarded for patterns with very long developmental periods.

``Maybe this is how science progresses: an initial mystery based on ignorance, then a discovery and a learning stage, and a final mystery based on knowledge. Sounds a bit like art." [14] Pp 25.

8. Acknowledgements

Many thanks to Ezequiel Di Paolo for supervision and to Peter Bentley for editing advise.

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Applied Generative Procedures in Furniture Design

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Abstract

This paper discusses an approach which combines different generative procedures with design methods as they are common in daily design practice: Two generative tools together with paper models, prototypes and „classical“ Computer Aided Design span the design process. The subject of experimentation is a specific class of furniture: CNC - manufactured, foldable objects for different seating positions, based on a material composition of thin plywood laminated with fabric and / or felt.

The generative tools described below have been developed with the macro programming facilities of the CAD-software I-DEAS. One tool can be used either for systematic exploration of the search space or as a source for inspiration, depending on the preference settings chosen by the user. The other tool is made for the elaboration of details of the generated designs and for preparing production. The prototypes of these tools are still in an experimental stage and just in use to be tested and evaluated. Therefore the charcacter of the following text is more descriptive than analysing.

1. Occasions

About two years ago, while working on my Master Degree Thesis about Genetic Algorithms in Design, I was looking for a suitable example for developing a small generative program to illustrate some of my hypothesises. At the same time Timm Herok, a friend of mine and student of Product-Design, started to develop a composite material based on fabric laminated on thin plywood sheets for Computer Numeric Controlled (CNC) production. The wooden part of the material is milled (mainly) with a 90 degree conic mill tool from one side leaving the fabric untouched. After the milling process the flat sheet can be folded and results in various three dimensional objects according to the milled pattern (see Fig. 1).

In a first short joint design project it was decided to limit the enormous space of possibilities given by this principle towards one very specific class of furniture. We only used milling patterns which are based on two bilateral symmetric splines – to create the basic form – and some straight lines as additional elements and one possibility to fix and to stabilize the folded 3D-objects. Despite this limitation of allowed patterns, the principle still was able to generate a variety of many different kinds of furniture but all speaking the same aesthetic language. The designs of two experimental prototypes, (see Fig. 2) which caused some attention on design exhibitions [1][2], have been realized with help of a generative program, which is the pre-decessor of the program presented in this paper.

The „c-labor“ of the University of Design Offenbach (Germany) [3] is running a research project concerned about the development of (also foldable) designs for mass customization [4] above the somehow boring level of choosing different colours or sizes. That this generative program will be presented on the exhibition of this research project indicates into one field where generative procedures are helpful and may become familiar: Integrating them into a design process to meet the needs and wishes of single customers and – at the same time – having enough performance to link many different individual design to Computer Numeric Controlled manufacturing facilities.

Fig. 1 (left): Stool Protoype – unfolded and folded (Timm Herok) –
Fig. 2: Two Prototypes on exhibitions in Cologne and Kassel (Markus Schein)

2. Tool One – Systematic Exploration and Some Surprises

The developed generative tool is divided into two program parts. The first and main part is made to discover potential types of furniture within the search space of the above mentioned type of pattern. The basic idea was that one shall either have the possibility to explore the search space systematically by reducing the random elements within the generative process or to use randomness to generate more or less unexpected events as a sort of inspiration for the design of new products. The restriction of using only one type of pattern provides one big advantage: There are only some few variables to be maintained within the program and therefore the question about how to organize the complexity of managing a growing number of variables to control the generative process could have been neglected.

2.1 Geometrical Representations, Stucture and Function

2.1.1 Basic Geometric and Design Variables

According to the simplicity of their construction two dimensional patterns – later used as guidelines for the milling process – are sufficient as geometrical representation of the objects. Therefore the main parameters of the objects genetic code are the coordinate pairs of the through points of the splines and the number of these points. The values of the x- and y-coordinates are always chosen by random, the number of these points can be userdefined or also be defined by random (within a range of 3 to 30 per spline). The symetric spline pair basically determines the shape of the later object and therefore also its potential use (as stool, chair, easy chair, chaiselongue, for one, two, more persons...)(see fig. 3).

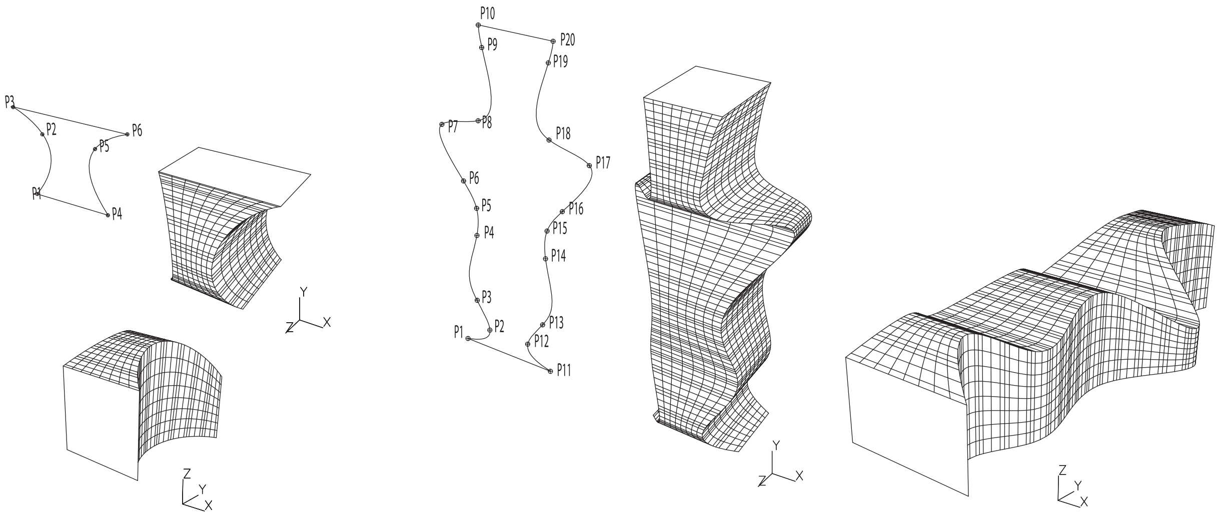

Fig. 3 (left): Two generated objects – the left one maybe could a stool, the right one an easy chair.

2.1.2 Control Variables – Sheet Measures

For a further influence on the generative process, the user can set the board size he then wishes to use for production. In x-direction (perpendicular to the main spline indication) the according variable is equivalent to the exact measure of the sheet. The variable storing the value for the y-direction represents only vaguely the according measure. The actual value depends on the type of folding technique used to close and to stabilize the form (see fig. 4). Mostly this is to be decided at a later stage of the design process.

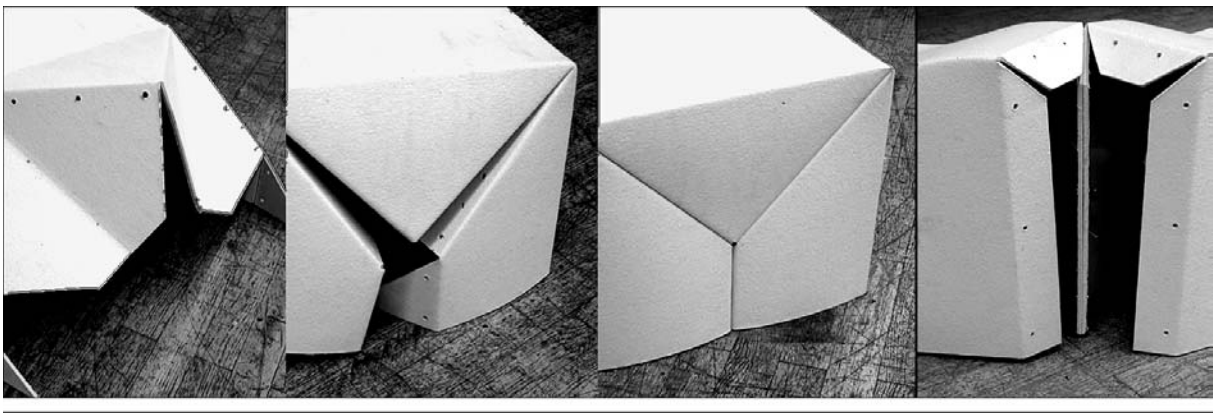

Fig. 4: Two possibilities of closing a form: at the end (three pictures left) and in the middle for building a row of objects.

2.1.3 Control Variables – Spline Generation

To keep the number of variables for user interaction low, there isn‘t provided any influence on the control points of the splines (NURBS) – the standard preferences of the CAD-Software are used. This has the disadvantage that the splines may get very extreme shapes – with an unfortunate random distribution of the co-ordinates of the through points. Sometimes too extreme to generate useful objects. Therefore the program offers four control variables to compensate these effects.

With one variable, the user can determine a minimal distance between the outer border of the sheet (in x-direction) and the nearest through point. This is equivalent to an approximate minimal height of the generated object. He can also define the minimal distance between the spline pair, a rough equivalent of the smallest width available for seating (see fig. 5).

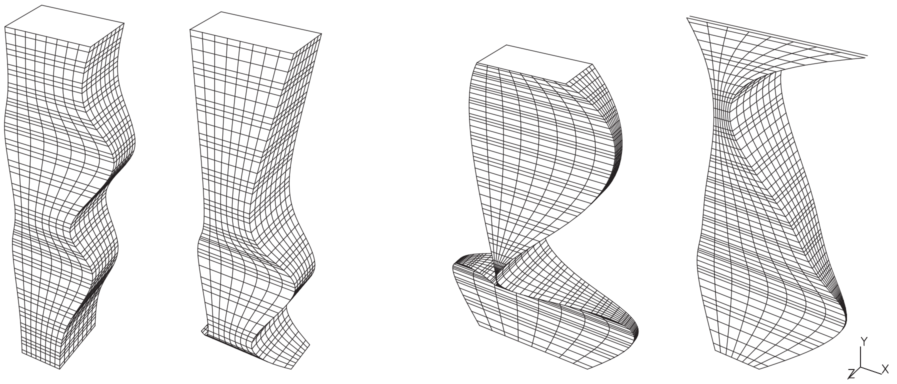

Fig. 5: Four Objects generated with the same settings but the first two ones require a certain minimum height and width, the others do not.

Finally there is the possibility to require a minimal distance between subsequent through points. In y-direction this helps to minimize the risk of self intersecting splines, in x-direction it guarantees that splines have always at least some curvature.

These control variables are all depending on each other – for internal constraint handling the sheet measures are set as dominant, in case of conflicts the other values are adopted accordingly. They do not allow to control the generation of the designs exactly, but – at least – they offer the possibility to take some influence on the basic constraints. This may seem to be unsatisfying but compared with common design processes we are still on the level of sketching, of approaching some idea. Within this stage we usually do not care too much about precision in order to keep the flow of ideas. Due to the precision of computer representations, the generated objects tend to seem much more advanced than they actually are.

2.1.4 Control Variables – Symmetry Operations

Besides the rough control of basic constraints, symmetries have most influence on the potential use of the generated objects and of course on their aesthetic quality. The use of symmetries refers to the whole spline (or some segments of it) along its main indication (in y direction – along the object).

The options are to prohibit the use of any symmetry operation, to use only bilateral symmetry, only translational symmetry or to use both in combination. These settings can be defined by the user or again be left to random choice.

Some Examples: Preference Settings which exclude the use of symmetry, which have about 6 through points per spline and a sheet size which has a bigger length than width, cause objects which indicate to an use as an easy chair for to lie on for one person (see fig. 6).

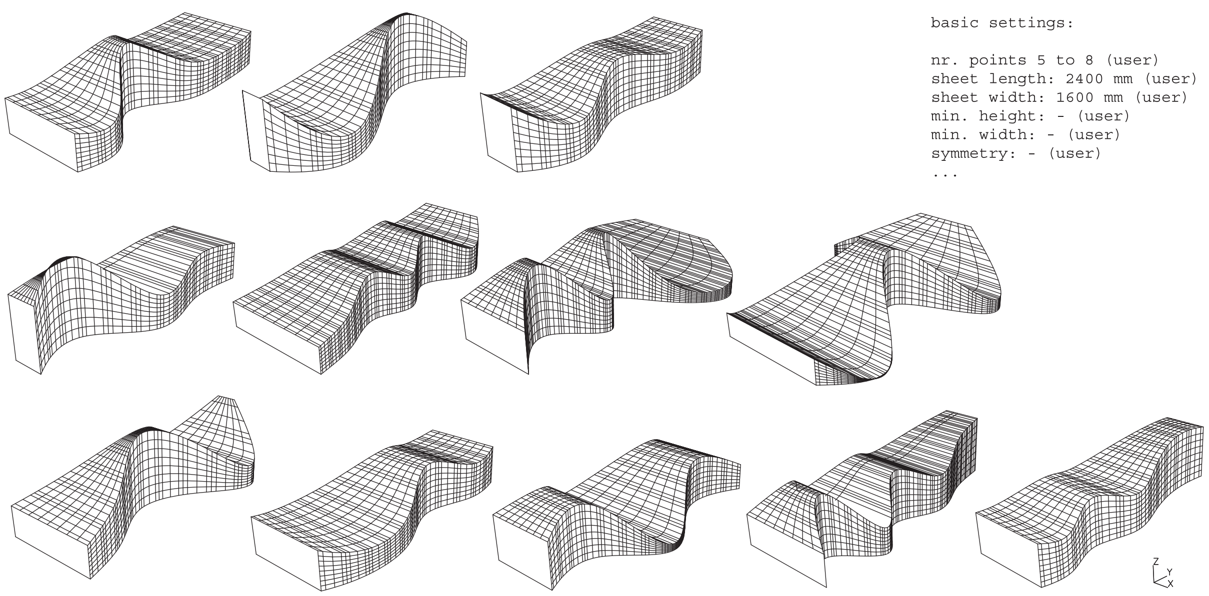

Fig. 6: Twelve more or less promising models for easy chairs ...

Similar settings with a different sheet size (width bigger than the length) and some more control about minimum width and height cause objects which may be developed toward easy chairs for seating (see fig. 7).

Objects for two people – sitting or lying face to face or back to back – are the result of setting which uses one time bilateral symmetry along the splines (see fig. 8).

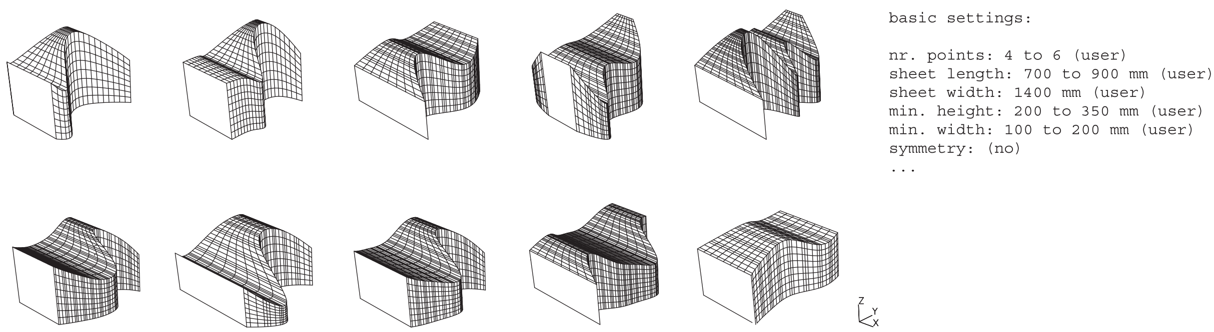

Fig. 7: … and some more potential easy chairs, this time more for seating positions.

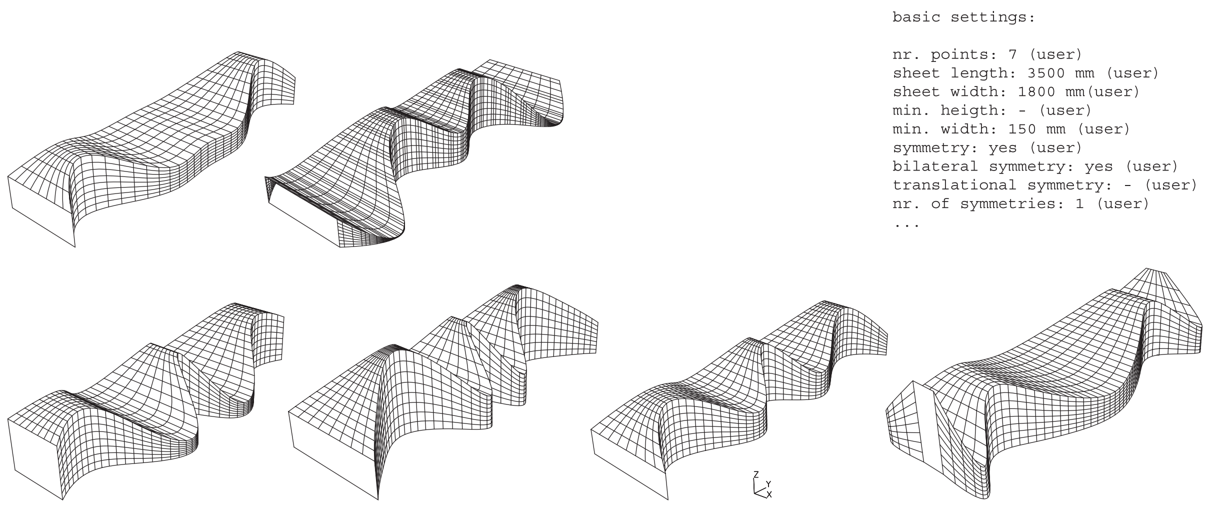

Fig. 8: For two person.

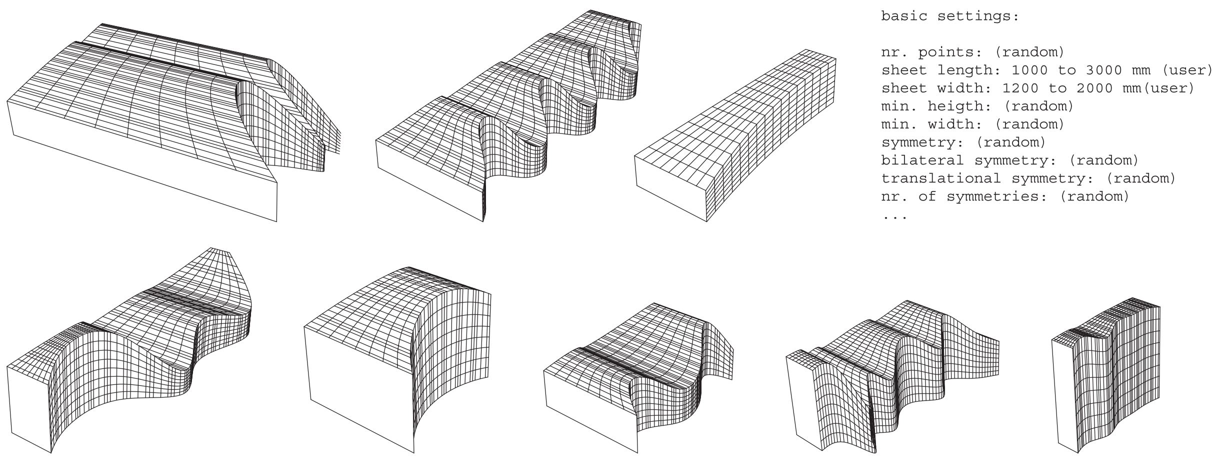

Fig. 9: Models generated with basically random preferences.

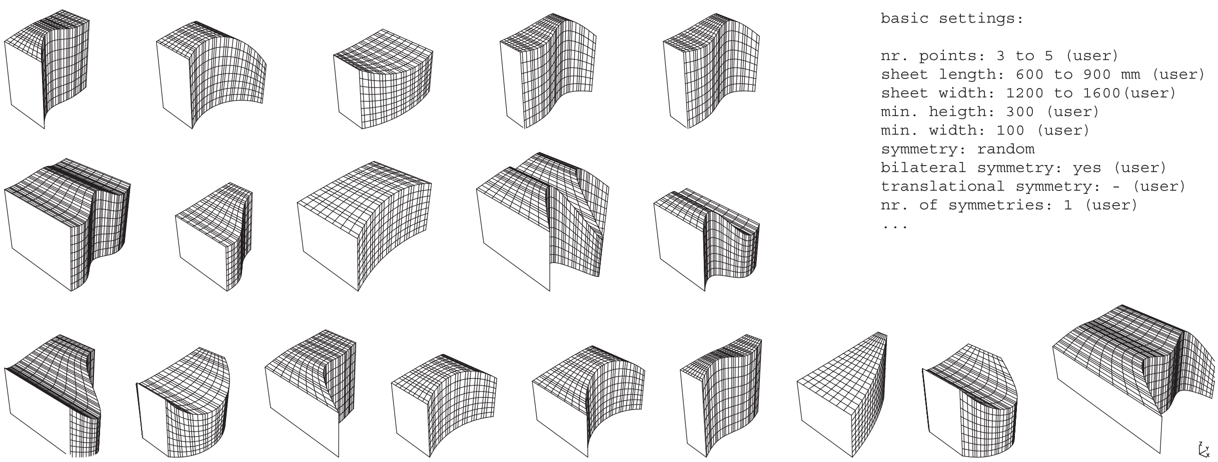

Fig. 10: Stool variations generated with basically userdefined preferences.

Other settings may result in other types of objects, for a lot of them the use still needs to be found or invented. The more of the preference settings are left to random choice, the more objects of this type are generated, offering the opportunity (with some luck and patience) to find some new potential furniture (see fig. 9). The tighter the settings are, the more of them are restricted by the user, the more the generative process tends towards systematic exploration of one type of object (see fig. 10).

The base of the generation of the 3D-objects are reference points homogeneously distributed along the splines of the 2D-pattern. The user can decide whether he wants to represent the objects with the same number of points (see fig. 11) as through points used for the generation of the splines. He can also decide to use less or more points. The use of less reference points simplifies complicated forms, the use of more points allow to work in more details of (especially) simple forms.

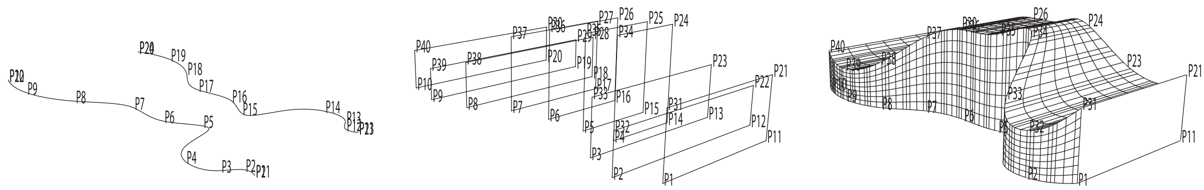

Fig. 11: Model generated with an equal number of through points and reference points.

3. Tool Two – Elaboration of Details – Modelling – Production

In this tool it goes the other way round: now the three dimensional data are used to elaborate the generated designs, the 2D-pattern is only generated if necessary for output purposes.

3.1. Shaping Generated Forms

The coordinates of the wireframes of the 3D-forms are all stored in a library. In this tool, these data are the input to exactly repeat the construction of the chosen object. Then the user can manually change the genetic code, now consisting in triples of coordinates. After having finished the modifications, the object is going to be constructed again, now using the modified genetic code. This way the form can be shaped, worked out in more details. There is the choice to have the symmetrical properties inherited in the objects maintained or rejected. Every time an output for modelling or protoyping is required, the 3D- dimensional object is transferred to the according two dimensional pattern.

3.2 Output for Paper Models (Scale 1:10)

First experiences with this kind of modelling have shown, that it is hard to judge the quality of the objects on the computer screen – on one hand because of the enormous amount of generated objects and on the other hand because of their similarities. It has shown, that paper models in the scale of 1:10 (with uncoated paper of about 120-160g/m^2) are simulating surprisingly good the material behaviour of the real object when being folded. (see fig. 12). If it is hard to fold the 1:10 models and if it starts to crumble it doesn‘t make any sense to go into 1:1 protoypes. There will be too much tension in the material and there is a high risk that it will be damaged. The paper models also can be used to catch a first impression of the anthropometric qualities of the objects: two rough paper models, representing 50 Percentile male and female, are the first probands to test the objects confortability. (see fig. 12).

Fig. 12: First tests about anthropometric quality and material behaviour.

The data output for producing the paper models is simple: A 1:10 snapshot of the two dimensional pattern is automatically taken, transferred into an Encapsulated Postscript File (EPS) and printed to be folded.

3.3 Output for Protoyping (Scale 1:1)

The same procedure is used to generate the data for prototyping. Because EPS-files are also able to store vector data, they can be used as Input for the CAM (Computer Aided Manufacturing) software which is manoeuvring the milling process. However, recent experiences have shown, that this procedure works in general, but causes some problems especially with a certain kind of CAM-software in combination with 5-axis-milling centers, so that this output method probably has to be changed.

For protoyping, two different kinds of milling patterns are generated: The first pattern for formatting the plywood-fabric sheet and to mill the holes for keeping the form together and the second is to mill the folding lines. Up to now, the milling path for the holes has to be added by using the CAD-System in a conventional way: The required paths are placed in generated pattern manually, because the distribution of these holes is not only a static but also a aesthetic question, a question of what kind of technique shall be used: belts, tubes, visible, not visible ... .The same goes with the folding pattern used to close or connect objects.

At the moment, the patterns shown in figure 4 can be automatically generated. If an other pattern shall be used, this also has to be implemented manually with the CAD-System.

4. Summary

For the development of a generative tool to be used beyond the scope of research, these foldable objects have been a lucky case. In the family of furniture they are a extraordinarily closed system with a rather low complexity, maybe comparable with Bentleys tables [5] or Dawkins „Blind Watchmaker" [6]. Even if these two examples use different methods for generating variety (and for selection) than the presented tool, the generated objects are also clearly identifiable as belonging to one very specific kind.

In the real design world, such cases are rare exceptions. Usually we don't know in advance, what kind of materials, forms, fittings, connecting pieces, etc. we will go to use. But more uncertainess about these things also requires more freedom in form generation which – at the end – means more variables to influence, more complexity, more relations between more parts, more complicity which will make the design of a generative software for a broader, multi- purpose use to a task comparable with the development of huge CAD-Systems like Unigraphics, I-Deas or Catia – where lately the philosophy of the company selling the software decides about their – and therefore our – limitations in work [7]. But an other way also seems to be possible: Design education institutions recognise the chance which may be embeded in Generative Design and teach their students other modelling and description techniques such as formatting and programming languages in addition to the usual sketching, drawing and modelling. This would enable people to invent their own generative programs fulfilling their specific requirements.

Wherever the development may go to, still on the prototype level, the first challenges for the described „Foldable Furniture Generator" towards an extension of its possibilities already appear, especially for generating other types of patterns creating completely different kinds of furniture. How big the temptation may be, for this time it is decided: a small extension towards objects, which can be folded in for directions. Then the search for a furniture manufacturer, daring and confident enough, to give the „Foldable Furniture Generator" and its objects a chance in the real design world.

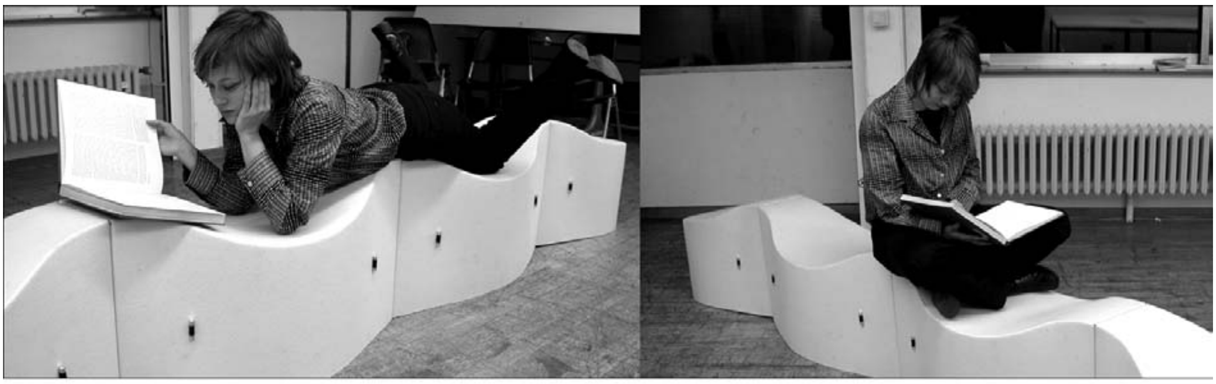

Fig. 13: „Feltworm" – Generated and realized prototype

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Using Social Interaction in Generative Design of Shared Virtual Spaces

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Abstract

The proposed paper outlines research findings in the field of generative design of visual virtual chat spaces.

It discusses social interaction as a central determining factor in the generation of virtual spaces through and for chat communication on the World Wide Web. Social interaction in a chat room is based on communication using written text. The research and design results of this project involve the translation of chat statements into three-dimensional virtual objects according to

- criteria derived from theories of virtual and social space,
- the production of space through action and interaction of the users of the interface and
- the translation of the components of written text (words and characters) into three-dimensional virtual forms.

The generation of a dynamic, virtual, social structure is based on criteria deduced from systems of interaction within social space. The visual social structure, reflected in the shape and spatial relation of the three-dimensional objects, evolves as source for feedback processes and therefore as "re-generation" of social interaction.

This paper documents the design, implementation and evaluation of the described system. It represents an outset and a first manifestation of a new project in cultural-differentiated user-interaction-centred generative approaches in interface design of chat room applications.

1. Introduction

Using social interaction in the generative design of shared virtual spaces seems quite broad at the first glance. In the project and research findings described in this paper I used social interaction in form of textual communication to generate a shared virtual space. In the visual virtual chat application, the communication process itself re-generates a shared virtual environment. Examining theories of social interaction in relation to space led me to the hypothesis that many examples of shared virtual spaces reveal structural similarities to social space and social interaction. These spaces exist only as result of the users action and interaction. Social interaction in shared virtual space may produce different expressions and reveal structures that may have been implicit but not visible or identifiable in social interaction patterns in physical space. I have examined the generative potentials of social interaction in a chat room with regard to the generation of a shared and dynamic virtual space. In this chat space, the statements of each user are made visible in a three-dimensional VRML-World using abstract shapes. I deduced the generative criteria for this chat space from theories of interrelation of different modalities of "space".

Our senses seem to tell us we are "living in space", but research findings in the fields of physics [12], sociology [8] and philosophy [11] claim that we constantly (re-)construct our space, environment and reality. According to these findings, the feeling of "living in space" is a result of mankind's history of development and constitutes just a learned acceptance of one interpretation of the world. Our view is influenced by Newton's [9] definition of absolute space (also referred to as the definition of space as a box). The theory says that space is a container and that all matter (living or non-living structures) are located within it. Matter is affected by space but does not effect the space surrounding it. This view was reflected in science, culture and architecture until Einstein [12] proposed the concept of relative space. In Einstein's physics, space is just a relation of positions of things to each other. Space is not absolute but relative to the system of reference. Matter, space and time depend on each other and can't be observed separately.

The idea of relative space was adopted by other disciplines in the sciences, as well as art and architecture. In the social space theory, the idea of relative space is appropriated and extended by Martina Loew [8]. The theory says that social space is produced by the human beings interacting with each other. Space does not exist "a priori" but is continuously reproduced. The current state of space is a temporary product of the order of matter on the basis of action. Social space is built upon the relations of human beings, institutions and objects.

Human beings interact. Our environment is defined by the interaction of different living and non-living structures. Social interaction of human beings is largely based on verbal and non-verbal communication. In chat-rooms, social interaction is based on written verbal communication. However, the chat space I want to discuss in the following sections also relies on visual communication and feedback processes between visual and verbal communication, as well as spatial recognition of the virtual environment constructed by the actions of each user. As an ongoing process this project is now entering a phase in which not only the computer-represented aspects of language (ASCII-characters) are taken into account. Natural language itself, and its use in chat communication, is proposed to serve as a source of generative seeds and principles for the design of shared virtual spaces.

2. Scope

To start, I would like to introduce some terms I have used in the description of the experiments I have done in the field of chat communication. The type of a visual virtual chat space that I want to discuss in this paper is a new concept in the field of shared virtual spaces. The visual virtual chat space has a different approach than that of MOO's, virtual communities, avatar worlds or collaborative design spaces. The main distinguishing characteristic in these shared virtual spaces can be found in the form, process and result of social interaction. A traditional chat room's social interaction is clearly restricted to verbal communication. A visual virtual chat room has another dimension. In addition to verbal communication, a visual component adds another component to the social interaction process. But this visual component is not a separate world, such as in avatar worlds, in which users can interact with one another separately and independently from the text-chat component. The text and the visual component in the visual virtual chat space are bound together and each can not be transformed independently of the other. They depend on each other because one component (text) influences the other (visual) component directly. Strictly speaking, the verbal component produces/generates the visual one.

3. Generative processes in shared virtual spaces

The processes of generation of shared virtual spaces can be derived from the modes of interaction inherent in these spaces. The generative processes I examine are worked out from the principles of social interaction in chat rooms. In this example, users of a chat room application generate a shared virtual space through textual communication. This space of communication is mapped using the components of text (words and letters of the alphabet). The dynamic output (virtual environment) in this generative process relies on two components. The first is the programmed interface and algorithm as a framework for the user's interaction and the second is the input of the users themselves. The conceptual framework for the generative processes used in this visual virtual chat space is derived from the idea of a relative social space, the idea of remote presence (place versus space) and the dynamics of the communication process in chat applications.

The sharing of virtual space through social interaction connects different physical spaces. The symbolic and remote presence of the participants carries the possibility for generation of a collective shared virtual space. This non-physical space is dynamic and changing through further action and interaction. Interaction itself is the seeding process that produces complex virtual expressions aimed at expressing the shared virtual space visually.

3.1. Shared Virtual Space

"Shared virtual spaces are complex multi-user online environments that use strong spatial metaphors for navigation, communication and interaction scoping, and object manipulation and may support 3D immersive displays."[3] In addition to the preceding definition, shared virtual spaces have, according to Disz [3], the following capabilities: immersion, sharing of object and virtual space, co-ordinated navigation and discovery, interactive control and synchronisation as well as interactive modification of the environment. In the following discussion, I have assumed these definitions of shared virtual spaces with different emphasises.

How do I define a shared virtual space? The beginning of my research formed an investigation into theories of space. The interrelation of different theories of space (evolved in the developmental process of science and philosophy) forms a framework for the perception of space. Ideas about space and the actual perception of spaces are defined by the oppositions relative and absolute space as well as physical and psychological space.

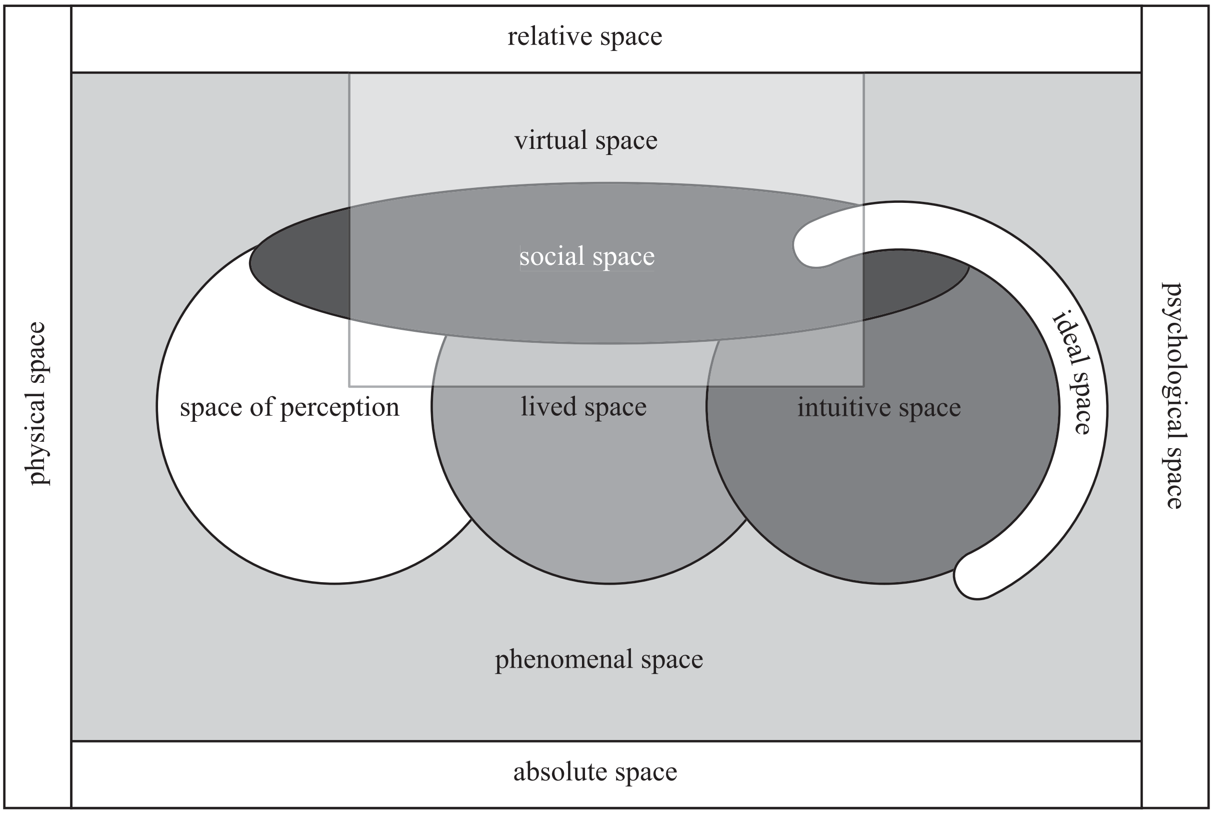


Figure 1 model of different related spaces, redrawn from Heymann, (pp.65) [6]

The interrelation and permeation of spaces in our perception makes it possible to extract criteria for the generation of a shared virtual space. Rosemarie Stroeker [11] defined the process of perceiving space as an inter-permeating, transient and merging process including (but not limited to) the space of perception, space of action (lived space) and intuitive space. The permeation of spaces within social interaction of human beings can be seen as a potential seed for generative design processes. The ability of a single human being to be physically situated in one location but mentally (psychologically) in another is an indication for the existence of different permeating spaces. This phenomenon makes it possible to form social networks and to build up social spaces between places and people who are physically apart from each other. A shared virtual space is networked. Networked spaces are perceived in a non-linear manner due to the simultaneity of the perception and presence of different spaces at the same time. The possibility to form or inhabit different spaces simultaneously is the first condition for generation of a shared virtual space on the basis of social interaction.

According to figure 1, even virtual space takes part in the inter-relational theory of space. "The virtual is opposed not to the real but to the actual," according to Deleuze [2]. Virtual space is an alternatively generated reality. Virtual space is just a view on real space, just a part in the inter-relational field in the theory of space. Possible structures of virtual space can be visualised just like other types of real space e.g. physical space. But the process of visualisation/actualisation of the virtual makes structures visible which are not perceivable in real/physical spaces. The possibility of visualisation of the structure of virtual space is the second condition for the generation of a shared virtual space.

In the process of the constitution of shared virtual spaces, an individual plans and acts in one space, but the result is shown in another space. The individual occupies two spaces at the same time and perceives each of the spaces differently. The individual is physically located in one place and has a remote and symbolic presence in the other space. Mapping individual space is the third condition for the generation of a shared virtual space.

Due to a different constitution of these (physical and virtual) spaces, the action of the individual has another impact on the social structure of space. In the real/physical space, our actions are determined and guided by given structures. These structures are mainly institutions which are build up collectively and result in a spatial representation, which is a fairly stable result of this process due to a reproduction of the same structures in the same way. The constitution of the shared virtual space that I describe shows similarities to such structures in real/physical space but there is no stable result of this process. Our own actions define the space that in turn determines the context for subsequent action. One can see a direct impact of one's action on this temporary formation of space, which one couldn't observe in real/physical space. The constitution of a shared virtual space seems to be determined and guided by the participants whereas in real/physical space the spatial structures and constraints seem to be socially given and fixed. On the other hand, the shared virtual space can only be accessed through an interface, which is also a structure that guides our action and interaction. The shared virtual space I will describe is dynamically expressed in the interactions between users and the structural definition of these interaction spaces but within the boundaries of a framework - the interface. Social space is an expression of the meeting of individual spaces in interaction. The mapping of individual action and social interaction space is the most important prerequisite for the generation of the shared virtual space.

3.2. Social Interaction in a Shared Virtual Space

Types of social interaction in shared virtual spaces can be divided into verbal and non-verbal communication. Verbal communication in shared virtual spaces includes spoken and written language. Non-verbal communication refers to physical language (gesture or mimic). Correspondingly, interaction in shared virtual spaces can be "communication-centred or artefact-centred" according to Xiaolong and Furnas [13]. "While the former focuses on contents and implications of exchanged messages, the latter emphasises the mutual understandings of artefacts and users' activities related to artefacts." [13] This strict distinction between communication and artefacts does not apply to the shared virtual space that I will present. On the one hand, the chat application bases on textual communication. But on the other hand, the users generate artefacts as visual expression of the communication process, which influence their activities.

Referring to Figure 1, social space takes a special position in the relational field of spaces since social interaction involves spaces of both perception and cognition (spatial sensation and behaviour) as well as ideational/imaginary space (social conventions or implementation of abstract ideas of space). Social interaction is based on our sensation of space, but this sensation is also related to our social and collective view on the idea of space, which might differ from culture to culture. In turn, the personal view and perception of space influences the collective view of space amongst the participants in the shared virtual space. Every interaction re-generates and re-structures social space. Social interaction in the shared virtual space that I refer to is able to actually produce (generate) changes in the visual environment of the space in ways that are not possible in real/physical space. Social interaction generates new relations between the virtual objects and moreover re-structures the virtual environment. The re-structuring of space is made visible through the interrelation of verbal and non-verbal interaction. This positive feedback process can be observed in the shared virtual space I bring up later on. (Figure 2)

This feedback process is a result of the process of self-organisation within the chat system. The self-organisational process is characterised by a non-linear communication flow and movements towards dynamic attractors (probably as many as there are user in the system!). Spontaneous self-organisation is difficult to observe in text chat systems that are programmed for non-linear and parallel interactions under local system conditions (World Wide Web connection speed, server-regulated order of incoming text to display on the screen). Text-based chat applications provide view visual indicators on social roles/social settings or possibilities for giving feedback.

In contrast, in a visual virtual chat space social interaction is not only expressed in the textual communication flow but can also be perceived in the visual environment of the space. Social interaction can be stimulated by the visual environment, which is expressed in the spatial relation of the virtual objects. Changing relations between the virtual objects help to build up an awareness of the "social setting" of the virtual environment. Even those interactions within the shared virtual space in which one does not personally participate have a visible effect on the environment one perceives. One could say that social interaction in the shared virtual space is not just object-orientated but environment-orientated. The relations between the virtual objects are dynamic. Furthermore the interaction-dependent spatial relations are the seed for continuing social interaction in shared virtual environments.

The interface for the visual virtual chat space I am describing is on the one hand the point of access to this space and on the other hand the structure upon which the space is generated. The chat space interface embodies special social conventions and structures to guide and map personal action and social interaction in the form of textual input, an algorithmic visual display and ordering system and the self-organising process of the communication flow continuing in textual inputs and changing visual outputs. The shared virtual space is self-organising within the constraints of the given framework - the interface. The interface is on the one hand limitation but on the other hand the only way to access the space, which is in fact generated within and through the process of entering the space.

The qualities of social interaction mentioned above constitute the seeds for the generation of a shared virtual space. The interface is the structure to access the space and guide the interaction. The actual expressions of this space are generated by the use of the interface and so by the users themselves. An example of the visual (three-dimensional) virtual chat environment is shown in the following Figure 2.

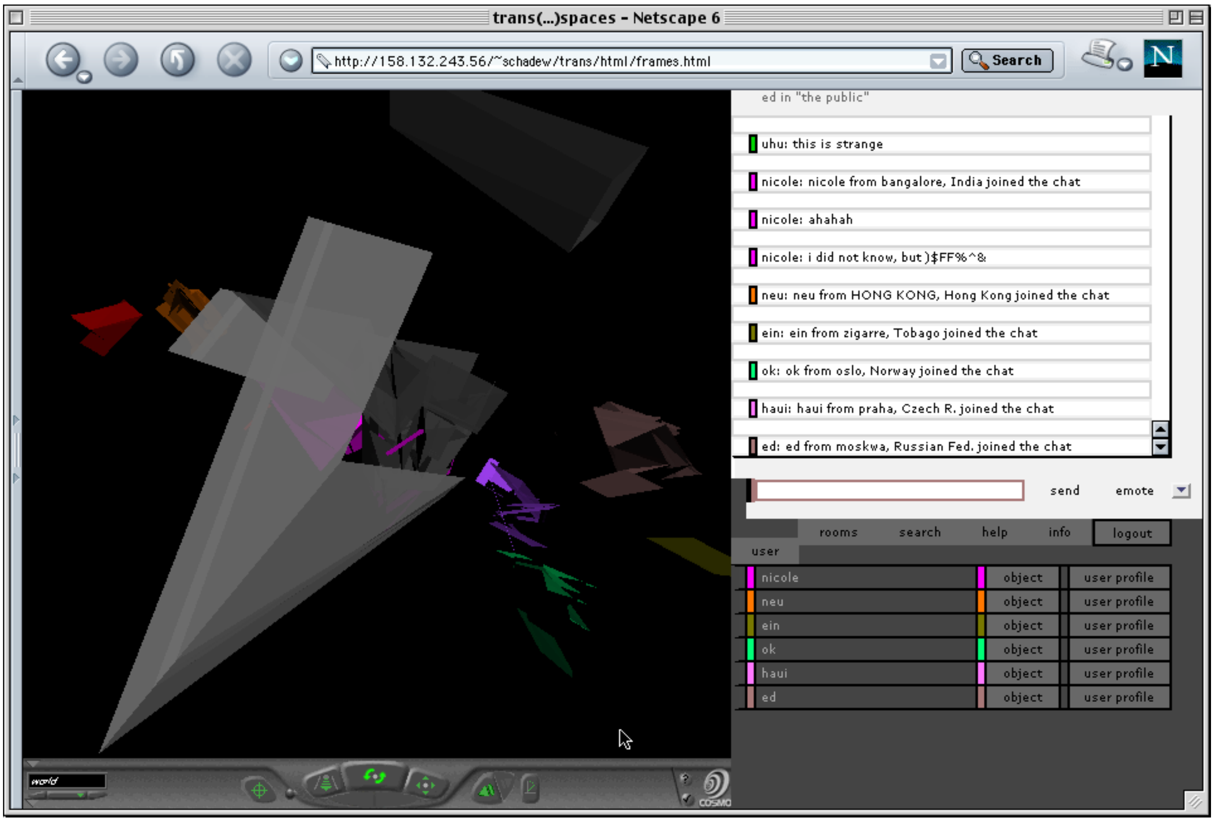


Figure 2 - Chat-Interface "trans(…)spaces"

3.3. Application

The generative principles extracted from the social interaction process have been applied in the design of the visual virtual chat space "trans(…)spaces".

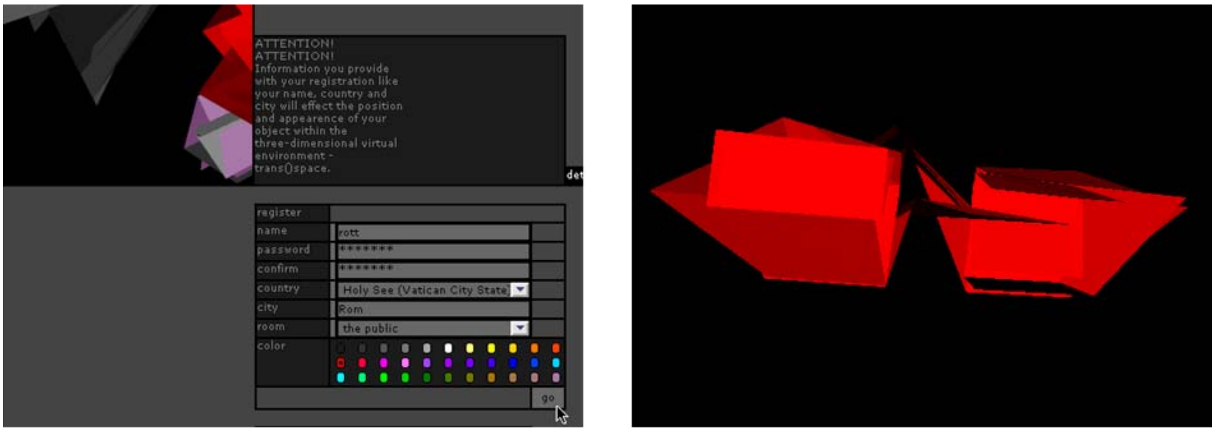
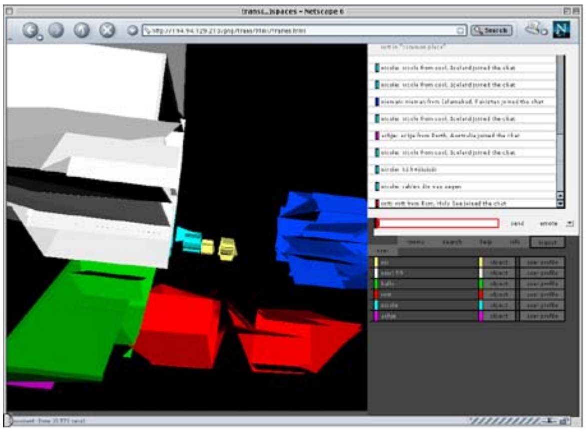


Figure 3/4. To log into the chat space the potential user has to input some information, including his/her name, a password, city and country of origin, and must make a choice as to the colour of his/her virtual object. All values influence the appearance and location of the user's virtual object.



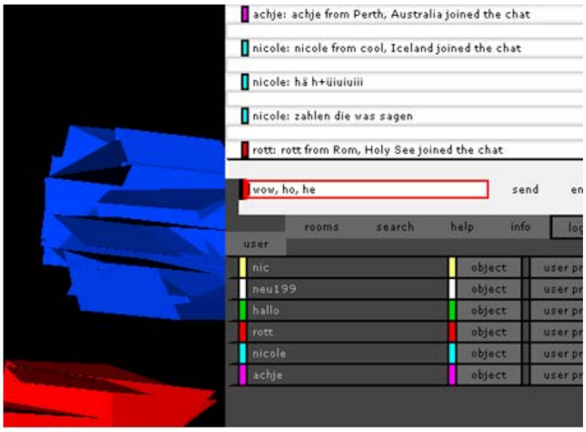
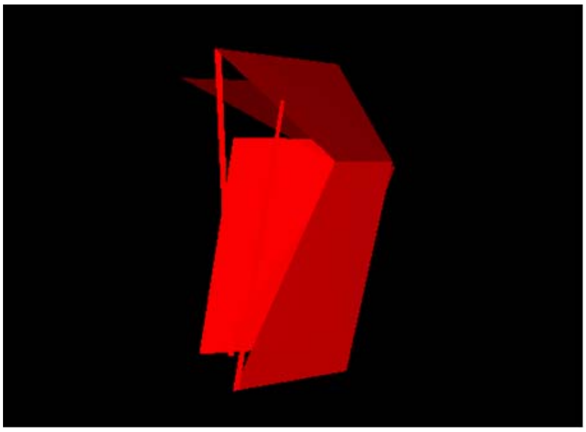


Figure 5/6. The entire sentence "rott from Holy See, Rom joined the chat" is processed to map the form of the object. The position within the virtual World (VRML) is calculated from the first characters of the name, the country and city. Each time the user enters a new string (statement into the chat-discussion), an algorithm computes the string into the new virtual object. The shape is changes with every new statement.



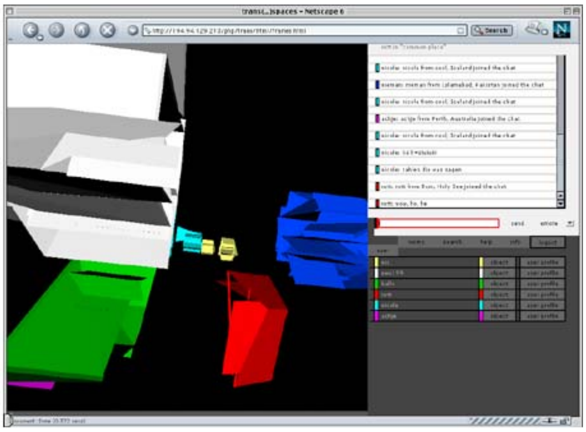


Figure 7/8. Not just the shape, but the entire virtual environment changes. The change in the environment is even better perceivable if a word matches an already registered one (within its first use). The form is moving towards the representative virtual object of the user, who said this word the first time. (Figure 11.)

The interface can be seen as an intersection - a connection of different spaces. The user enters from a real-physical place into a shared virtual space using the chat interface. I referred to the condition of permeating spaces as first generative prerequisite. The user enters the interface mentally. The body remains physically in the same place. The spaces are connected in the perception of the user. The origin of the user's object in the shared virtual space is related to the user's real/physical location but in the logic of the generated space. The login takes place on the basis of the data given by the user - name, country and place of origin.

The system for the interpretation of data and generation of the environment by the computer is drawn from the mode of interaction in a chat room - textual communication using characters of the alphabet, which form words and sentences constituting the medium of interaction. The computer's internal representation of characters is the ASCII System (Figure 9). In this conceptual model the user is origin of the communication process and output. The user is considered the central point of this model. The communication flows away from the centre of origin in a virtually undirected motion.

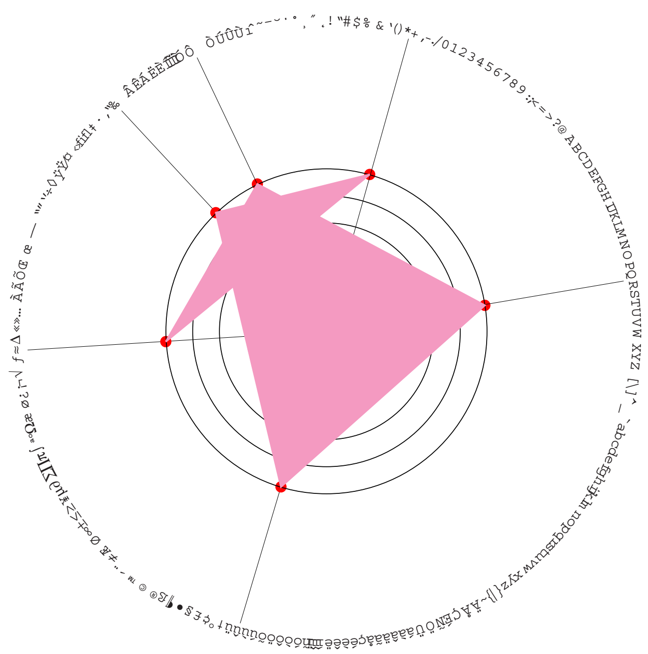


Figure 9. Representation of the modelling of a virtual object by an algorithm to extrapolate form from text using the ASCII system (computer intern character representation). The shape is created starting from the centre of origin, the user's login co-ordinates.

Based on this model of thought the computer generates the initial object according to the values input by the user in the login process. The co-ordinates for the generation of each object in virtual space are based on the ASCII values of each character used in the login information. The ASCII values are inserted in the VRML (Virtual Reality Modelling Language) "geometry Extrusion" function, which builds up the virtual object. (Figure 10)

```
Shape {
        geometry Extrusion {
                crossSection [
                # rott from Rom, Holy See joined the chat
                4.5 11.4, 4.5 11.1, 4.5 11.6, 4.5 11.6, 4.5 3.2, 4.5 10.2, 4.5 11.4, 4.5 11.1, 4.5 10.9, 4.5 3.2, 4.5 8.2, 4.5 11.1, 4.5 10.9, 4.5 4.4, 4.5 3.2, 4.5 7.2, 4.5 11.1, 4.5 10.8, 4.5 12.1, 4.5 3.2, 4.5 8.3, 4.5 10.1, 4.5 10.1, 4.5 3.2, 4.5 10.6, 4.5 11.1, 4.5 10.5, 4.5 11, 4.5 10.1, 4.5 10, 4.5 3.2, 4.5 11.6, 4.5 10.4, 4.5 10.1, 4.5 3.2, 4.5 9.9, 4.5 10.4, 4.5 9.7, 4.5 11.6,  ]

                spine [
                1.14 11 4, 1.11 10 1, 1.16 11 6, 1.16 11 6, 0.32 3 2, 1.02 10 2, 1.14 11 4, 1.11 10 1, 1.09 10 9, 0.32 3 2, 0.82 8 2, 1.11 10 1, 1.09 10 9, 0.44 4 4, 0.32 3 2, 0.72 7 2, 1.11 10 1, 1.08 10 8, 1.21 11 1, 0.32 3 2, 0.83 8 3, 1.01 9 1, 1.01 9 1, 0.32 3 2, 1.06 10 6, 1.11 10 1, 1.05 10 5, 1.1 10 0, 1.01 9 1, 1 9 0, 0.32 3 2, 1.16 11 6, 1.04 10 4, 1.01 9 1, 0.32 3 2, 0.99 9 9, 1.04 10 4, 0.97 9 7, 1.16 11 6, ]}}
```

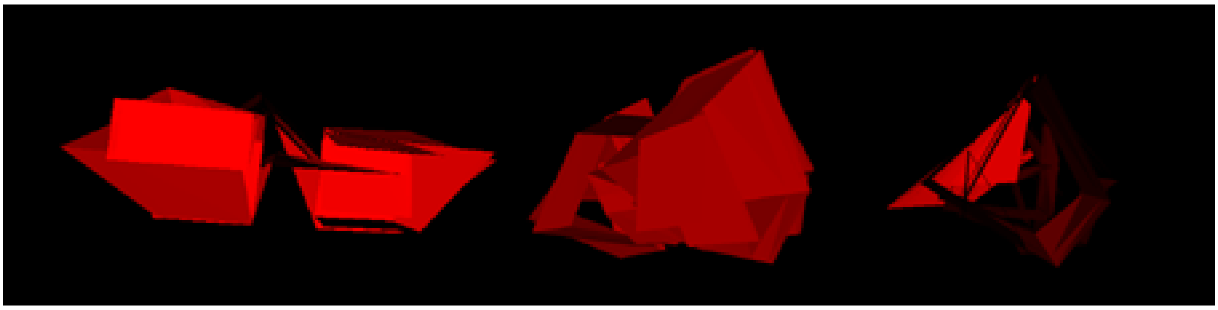


Figure 10 - VRML Code and interpretation of the code into the virtual object

With every following contribution of statements to the chat the virtual object changes. The object is an expression of the "social distance". Social distance is an important concept In defining borders of each person's social space and also borders of social groups. The object is equivalent to an individual virtual space around the person. In the chat system, the personal space is defined by propositions. Every proposition plays a part in defining not just the individual space but also the structure of the entire visual virtual space. The relation of a user to others in the space is dynamically defined by accordance with the keywords said in the chat. If a keyword matches one already held in the database, the object moves half the former distance to the object with the keyword-ownership. (Figure 11)

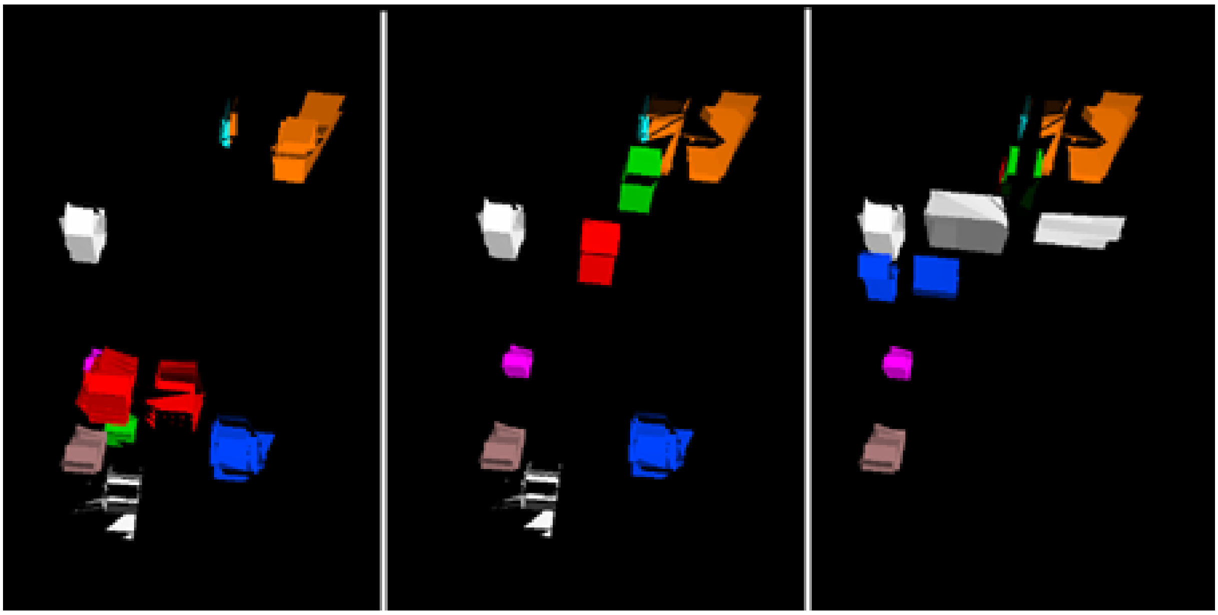


Figure 11 - movement

3.4. Evaluation

The two main types of generative output are the generation of the form based on the textual communication and the spatial expression of relations between these objects based on the thematic discourse (keyword accordance). Textual input and spatial output are interrelated in a positive feedback process.

The object is the expression of the individual space, but the movement and location of the object in relation to the others is an expression of the self-organising principle of the social space. Due to the constant repetition of the generative process, the objects are members of one "family of form" [4]. The generation of a dynamic self-organisational social space is only achievable through the interaction of the users. The interaction takes place between the users themselves but also between the structures of the chat system and each user. The users structure space through their social interaction. This space sets the environment for further action. Every interaction and positive feedback process has an influence on the further generation of the space. The space is "re-generated". Just one part of the social interaction, the verbal communication, is used to map the interaction space in the first instance, but verbal communication generates visual communication and visual communication "re-generates" verbal communication. The "re-generation" of space is a generative principle within this social network. I was able to observe with different users that the generated shape and position of the object had a direct influence on the following chat-statements contributed to the discussion. The object enhanced the interaction processes, which had a positive feedback on the object (similar shapes). Similarity of the objects and enforced grouping of related objects strengthens the social community.

In this application structures of social space, which have not been visible before and could never made visible in real-physical spaces, have been composed in a visual interpretation. The process-orientated generative design approach is used to involve the users action in the design outcome. The generative principle of repetition is utilised to strengthen the feeling of one community. The familiar and established social characteristics of chat rooms are enforced with the generative abstract representation of the chat statements. People entering the chat are equal in their visual representation to a certain degree. They can influence their representation. People with the same interests meet easily. There is a very high likelihood meeting people with similar interests according to their chat statement, object shape and relational position with help of the structuring interface functions, as well as by chance due to the self-organisational communication process.

Much work in generative design uses computational processes to compose generations of form. Afterwards, the designer chooses some examples from the variety of results. I use computational processes to let the user interact with the generative processes in the user design of a shared virtual environment. I, the designer, don’t choose the form or position of the virtual objects. Rather, I set the parameters in which the users generate their own environment. The space is generated dynamically and self-organisationally through chat communication within a given framework. The non-linear character of chat communication generates a new form of discourse, which is mapped in this application.

Attributes of networked spaces such as non-linearity, simultaneity and relatedness or connectivity are mirrored in the formation processes of this shared virtual environment. Networks are somehow paradoxical. On the one hand, they widen and extend the perceived space by opening up potential connections. On the other hand they connect places which are spatially far apart. In this sense they make distances appear smaller. Thus, the traditional perception of space is disrupted. There is not just one space, but many relational spaces constructed simultaneously. The permeation of different spaces is one generative condition of this chat space. From my point of view, this chat space builds upon a strong architectural metaphor, in which the architecture of social interaction is mapped into visual virtual architecture. This virtual architecture consists of relations and connections between the user. The user directly generates his or her environment.

4. Limitations, challenges and outlook

In its current state of development the chat system has technological limitations concerning the hardware and software that is used. The performance of the rendering is lacking in speed and the display in quality. The processing of the incoming strings of text and their transformation into the three dimensional environment is handled by the programming languages PHP and VRML. PHP reads the data from the MySQL database and writes it into the VRML function. The lack of build-in features for database connection in VRML makes it very difficult to handle large amounts of data efficiently. From the technological side, there may be solutions such as using JAVA3D. Some limitations may be overcome by new technological developments. But from my point of view the real challenge in this project lies in the research area of intercultural communication and the means that are currently used to communicate with other cultures using the World Wide Web and chat applications.

At this stage in the development of the application, the generation of form and environment is essentially limited to interpretations based on the internal system of computer-mediated communication (ASCII). From my point of view, a wider range of formal expression would be helpful in the context of intercultural communication. It seems to me that this challenge could best be addressed by an approach that involves even more utilisation of user action and interaction in the definition of visual virtual space. Issues that must be addressed in this context include the achievement of a more personalised or individualised expression whilst maintaining a recognisable "family of form" and a communal environment.

The usage of language in chat applications reveals dynamic cultural processes of communication and exchange. In chat rooms, the language of communication and exchange is mainly the English language. The use of English differs from user to user depending largely upon her/his cultural and linguistic background. Every user brings parts of her/his own personal usage of the language into the chat language, which bears little resemblance to "standard" English. Language as a cultural expression is dynamic (adoptive, morphologic) in cultural exchange processes. Culture is a process, with each culture living through exchange processes with other cultures. Is it possible and useful to make these processes visible and accessible in chat rooms? From my point of view, being aware of cultural differences can help in improving the process of intercultural communication.

Dynamic processes in the use of language are not easy to codify and map, but it is my hypothesis that these language differences can be expressed through algorithms, which generate differentiated visual output reflecting aspects of the particular use of language. I think the dynamic process within the use of language chat applications can become a generative seed for the visual communication of cultural processes.

The main generative approaches used in the design of this chat system are the process-oriented generation of shared virtual environments, the repetitive iteration of the process and the variations generated by the dynamic communication processes. This type of environment has no spatial precedent in other real/physical spaces. Communication appropriates space in this application. The process of communication demands a dynamic space. The space that is generated by communication is in constant flux as a result of the dynamic nature of the communication process.

4.1. Space of language in intercultural chat communication

These thoughts set the parameters for a new approach to the problem, which examines ways of mapping intercultural communication in a chat room application using natural language as a source of generative seeds. In the Project discussed above I have deduced generative seeds from statements within chat communication. The criteria I used as generative seed have been derived from the smallest components (characters) of the chat statements and the accordance of single words used in the chat-statements. As a next step I want to explore whether other aspects of language - not just characters, but words and the meaning of words (semantic) set in context (pragmatics) - could be used as generative seeds. A deeper understanding of intercultural communication in the World Wide Web and in chat applications requires studies into linguistic discourse in chat communication. Studies in discourse are based on the analysis of language beyond the sentence. Typical analysis of language, which are mainly based on grammar, syntax, morphology or semantics, are also important to the discourse analysis, but the context in which language is used influences the discourse to an even greater extend.

The first exploration of the idea of generative grammar were made by Chomsky [1]. Schmidt proposed that the same ideas may be applied to architecture [10]. Shape grammar is an analogy of architectural formation to language formation, which happens, according to Chomsky, with the help of two components: a reservoir of words on one side, and rules, which determine the combination of these words - the grammar - on the other side.

The users build their own virtual architecture within their discourse in chat communication. They are not just using words put together by a set of rules, which is grammar, but the grammar is put into a context and produces a new typology of communication. Every user has her/his own set of rules. Each participants use of language is culturally influenced and unique. But these typologies influence each other as well. The chat environment is a new social environment, which produces its own context. The use of language in this context produces new set of rules for the generative design of its virtual environment. This applies not only to a grammar of shape, but also to a generative visual discourse, a visible rhetoric or visual communication in virtual environments.

Zellig Harris introduced the term "transformation" in the context of linguistics [5]. He transformed metaphorical descriptions into a mathematical theory of language. This theory claims that combinatorial constraints are socially transmitted in evolutionary terms. Landa commented on the idea of combinatorial constraints: "Combinatorial productivity would not result from a centralised body of rules, but from a decentralised process in which each word locally restricts the speakers choice at each point in the construction." (pp. 219 [7]) In a local speech community some word orders are more likely or frequently to appear than others. The word order is socially obligatory information. Syntactical elements are not separated from semantics or pragmatics, because combinatorial constraints will not allow one to change one element alone but only in combination with each other. Combinatorial constraints are morphogenetic: "as new constraints emerge from conventionalisation of customary usage, changing the probabilities that words will co-occur, language structure self-organises as a process involving successive departures from equiprobabilty (i.e. randomness) in the combination formed by replicating norms." (pp. 221 [7])

Harris' theory of transformation has implications for the generative approach to intercultural discourse mapped in a visual chat communication. In chat communication, not less than three typologies are included in generating one space. At least two of them are related to the local cultural contexts of the individual users, which come into contact in a common pool to form one environment - the third typology. The new typology is generated through the new social community and its special/transformational use of the English language. This can't be achieved by the use of a universal grammar, so the environment is likely to be generated by combinatorial constraints. These morphological combinatorial constraints in the structure of chat language are self-organisational. The process of generation of a visual virtual space that is formed through chat communication has to be morphological and self-organisational, too.

New research experiments in the field of shared virtual chat spaces can be derived from the ideas of generative grammar and combinatorial constraints. The culturally differentiated use of the English language in chat applications can be used in research case studies on possible expressions of culturally influenced visual languages in shared virtual spaces. The use of language in social interaction might be able to be used to generate a shared social virtual architecture, which refers to unique cultural expressions (typologies) in one virtual community.

5. Conclusion

Visual virtual chat spaces are shared virtual spaces. They are characterised by their special social interaction process and outcome. This process is generative. The user of the chat interface generates the visual aspect of the environment. An algorithm in VRML translates chat statements into commands for the transformation and "re-generation" of the visual environment based on the ASCII values of the characters contained in the statement. Future work concerning shared virtual spaces will be related to natural language and the possibility of mapping intercultural processes through the differentiated usage of English to generate a culturally differentiated visual language in visual virtual chat spaces.

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Interacting unities: an agent-based system

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Abstract

Recently architects have been inspired by Thompson's Cartesian deformations and Waddington's flexible topological surface to work within a dynamic field characterized by forces. In this more active space of interactions, movement is the medium through which form evolves. This paper explores the interaction between pedestrians and their environment by regarding it as a process occurring between the two. It is hypothesized that the recurrent interaction between pedestrians and environment can lead to a structural coupling between those elements. Every time a change occurs in each one of them, as an expression of its own structural dynamics, it triggers changes to the other one. An agent-based system has been developed in order to explore that interaction, where the two interacting elements, agents (pedestrians) and environment, are autonomous units with a set of internal rules. The result is a landscape where each agent locally modifies its environment that in turn affects its movement, while the other agents respond to the new environment at a later time, indicating that the phenomenon of stigmergy is possible to take place among interactions with human analogy. It is found that it is the environment's internal rules that determine the nature and extent of change.

1. Introduction

The emergence of computation and digital technologies that have given rise to new ideas, have affected the architectural process, so the classical models of pure static, timeless form and structure are no longer adequate to describe contemporary architecture. Architecture is evolving, re-establishing its boundaries to adjust to a new medium, between the organic and the Euclidean that is considered supple. Zellner writes: "*Architecture is re-casting itself, becoming in part an experimental investigation of topological geometries [...] and partly a generative, kinematic sculpting of space*" [1]. There is a shift from a very deterministic view of the architectural object to a more dynamic one. This is evident in the work of Greg Lynn, where the object controls the whole process of form production. He describes the process as follows: "a*n object defined as a vector whose trajectory is related to other objects, forces, fields and flows, defines forms within an active space of force and motion*"[2].

With the introduction of dynamism, space and architecture are related to the notion of time. The connection between space and time establishes the idea of movement. In order for an architect to work with movement and form, it is essential to develop techniques that can relate gradient fields of influence with flexible forms of organisation. This implies a shift from a passive neutral space to an active space of interactions. Architecture can be conceptualised and modelled within a field that is understood as dynamic and characterised by forces that can be crystallised into forms. To an architect, questions of the surroundings are often questions that contribute to form. As Iain Borden poses it "*architecture […] is not made just once, but it is made and remade over and over again each time it is represented through another medium, each time its surroundings change, each time different people experience it*" [3].

By regarding pedestrian movement as an external force acting on the environment, this study attempts to explore the interaction between pedestrians and their environment, aiming to generate a form dynamically responsive to its surroundings, fully embodied within the context in which it exists. It intends to explore that interaction through an agent-based system, where two interacting elements can be identified: agents representing pedestrians and environment. It is demonstrated that the recurrent interaction between agents and environment can lead to a structural coupling between those two elements: every time a change occurs in each one of them as an expression of its own structural dynamics, it triggers changes to the other one.

The next section investigates issues from the field of architecture and biology, establishing the theoretical background upon which the research is based. Against this background, the basis of our exploration, the agent-based system is introduced and described along with the results of experimentation. We conclude with a discussion of the outcome of the whole process.

2. Literature review

In this section we look at movement and its effect on form generation in the field of architecture along with the relation of time to form, since in the interaction between pedestrians and environment we explore, movement is considered the medium through which the system evolves and the interaction is realized in time. We also refer to autopoietic and stigmergic theory from the field of biology that defines the relation between a unity and its environment in an attempt to find a mechanism of explaining that interaction, providing the theoretical backup of our hypothesis.

2.1 Architecture and animation

With the shift of architecture from a passive space to a more active, dynamic one and the advent of the computer in studios, animation has emerged in architectural practice as a design tool at conceptual level. It has enabled architects like Greg Lynn, Mark Goulthorpe of DECOI, Lars Spuybroek of NOX or Marcos Novak to develop dynamic and evolving design techniques. The use of animation has introduced duration and motion into static forms, so architecture is no longer based on the inert material properties. Design is viewed as a highly flexible and plastic medium in which architectural form constantly evolves through motion and transformation. According to Greg Lynn "*while motion implies movement and action, animation implies the evolution of form and its shaping forces; it suggests animalism, animism, growth, actuation, vitality and virtuality*"[4]. Simple parameters like scale, volume and dimension are no longer adequate to define forms; multivalent and external or invisible forces such as pedestrian and automotive movement, environmental forces like wind and sun, urban views and alignments, intensities of views and occupation in time affect form of a dynamically conceived architecture.

The issue of involvement of outside forces in the development of form is not new. The morphologist D'Arcy Thompson is perhaps the first person who attempted to describe the transformations of natural form in response to environmental forces [5]. He associated bodies and measures in such a way that specific dissymmetries and disproportions were maintained as events within a supple geometric system of deformations. In those deformations, particular information influences and transforms a general grid, so geometry becomes a more fluid and dynamic system to describe changing bodies through their appearances at singular moments. Additionally, another model that has been developed to describe the relationship between an evolving form within its environment is Conrad Waddington's concept of the epigenetic landscape. Kwinter writes: "*The epigenetic landscape is an undulating topological surface whose multiplicity of valleys corresponds to the possible trajectories (shapes) of any body evolving on it*" [6]. Any point change in that is distributed smoothly across the surface so that its influence is not locally related to any point. The introduction of any exogenous forces at any time will perturb the evolving on the landscape body from its determined trajectory and cause it to evolve a unique and original form.

For Greg Lynn "*this possibility of an animate field opens up a more intricate relationship of form and field that has not been possible before*" [7], so the form becomes the site for the calculation of multiple forces. In combination with time, topology and parameters it establishes the model that Lynn has developed to design in an animate space. A characteristic example of his work is Port Authority Gateway project, where the site was modelled using forces that simulate the movement of cars and buses, pedestrians and vehicles, underground and overground, land and water, each with varying speed and velocities. On the other hand, for Mark Goulthorpe of DECOI [8], animation is an emerging cultural phenomenon in which movement is implicit, while virtual dynamism is the essence of it. An example of his dynamic architecture is Aegis Hyposurface that actualises the idea of dynamic and responsive architecture capable of responding physically to stimuli from its surrounding environment. The surface deforms by capturing stimuli from the theatre environment and dissolving them into movements, supple fluidity or complex patterning.

The notion of dynamism relates space and architecture to time, making it amenable to human manipulation. Architects no longer limit themselves to the three dimensions of Euclid, but incorporate time in their design as the fourth dimension. Kwinter suggests that time functioning as a form of pure information "*is what makes the emergence and evolution of form possible by providing a communicative middle term –a metastability- affording exchanges and absorbing and transmitting tensions across the many and various systems of influence. Thus time is not just a novel or superadded variable; it is that agency which multiplies all variables by themselves*" [9].

2.2 Structural coupling and stigmergy

Autopoietic theory, developed by the Chilean biologists Humberto Maturana and Francisco Varela [10] concerns the theory that an organism, or unity, maintains itself within the environment through an internal delimited process. One of the key concepts of autopoietic theory is *structural coupling,* which defines the relation between a unity with either its environment or another unity. In a structurally determined dynamic system, since the structure is in ongoing change, its structural domains will also change, although they will be specified at every moment by their present structure. Provided that the unity does not enter into a destructive interaction with its environment, there will be compatibility between the structure of the environment and that of the unity. As long as this compatibility exists, environment and unity act as mutual sources of perturbation, triggering changes of state [11]. This ongoing process is called structural coupling. In Maturana and Varela's words "*we speak of structural coupling whenever there is a history of recurrent interactions leading to the structural congruence between two (or more) systems*" [12].

We can think of the unity's effect on the environment in terms of the notion of 'stigmergy' [13]. Stigmergy is an indirect interaction among social insects that results to the emergence of self-organization in them. When two individuals interact indirectly, one of them modifies the environment and the other responds to the new environment at a latter time; therefore individual behaviour modifies the environment, which in turn modifies the behaviour of other individuals. Grasse originally introduced stigmergy to explain task coordination and regulation in the context of nest reconstruction in Macrotermes termites.

3. Method

In this section we examine the action of pedestrians within an environment. Firstly, the agent-based system is introduced and described. Secondly, we explore the nature and extent of interaction between pedestrians and their environment through a series of experiments. Thirdly, the outcome of the whole process is discussed.

3.1 Description of the system

In an attempt to investigate the role of movement as an external force in an active space of interactions, we look at pedestrians' action within an environment. It was decided that agent modelling should be used as human movement can be successfully generated by applying simple rules that describe the behaviour of individual agents [14]. These simple rules result in a complex overall behaviour. Each agent is autonomous and seeks to modify its environment in a constant interaction with it. Taking into consideration our hypothesis that refers to structural coupling, it was indicated that the environment had to be constituted of components in order for us to be able to identify changes in structure. This led us to the use of a grid, since it is easily transformable both locally and as a whole. Agents and environment are regarded as a system –we refer to it as an agent-based system- since they constitute a complex whole, where two autonomous unities with internal rules interact together to achieve a certain goal: influence each other.

The choices already made for using agents and a grid to represent the environment determined the nature of interaction. The agents move independently on a two-dimensional grid consisted of blocks. By using an array of elements, a simple surface is created based on a geometrical simple form: a block. The agents modify their environment by translating each block they are standing on at the time, along with their height. The “identity” of the block –its position on the grid- can be established by rounding agent’s location (x and z coordinates) to the nearest integer.

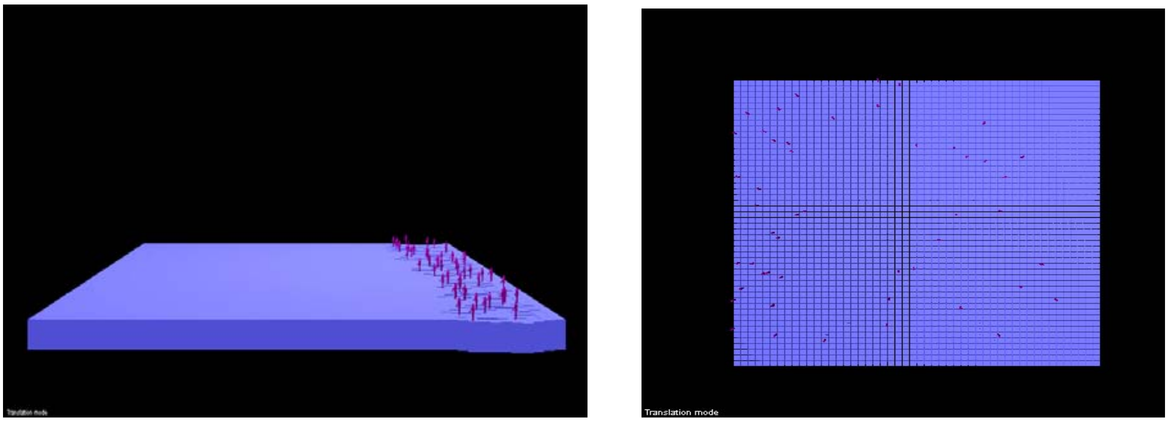

Figure 1: (a) Perspective and (b) top view of the agent –based system.

In pseudocode, the following simple process defines the interaction between agents and environment:

Loop

Find the grid reference of the block you are standing on by rounding your current location to the nearest integer.

Move a little bit.

Find the new block you are standing on by rounding your location to the nearest integer.

If the new block is different from the first then

Find this block’s height.

Translate the new block you have stepped onto

Translate your height along with that block.

End if

End loop

In this way the agents have knowledge of their environment, while the structuring of the environment caused by agents’ activities influences in turn their movement.

The interaction between the agents and their environment is explored through a series of experiments, the most interesting results of which will be presented in the following section. Those experiments focus on movement (random movement and movement based on vision) and its effect on the whole process, and on the extent of interaction agents-environment along with the result of this interaction. For the purpose of producing an experimental model, variables are established that can be manipulated to produce different conditions for comparison. Through using a set of parameters that define the relation between features of agents and features of the environment, the extent of interaction is determined and the initial environment is modified in each individual case creating a different visual effect. Those parameters are: speed and initial position of agents, height difference between blocks [15], sink height of a block each time an agent steps onto and maximum depth the block can reach.

3.2 Theoretical set of experiments

Movement is the medium through which the system evolves and the interaction is realized in time. In this section we will review experiments with random movement. The agents move independently on the environment. Each one moves forward and changes direction of movement gradually every 10 steps it takes.

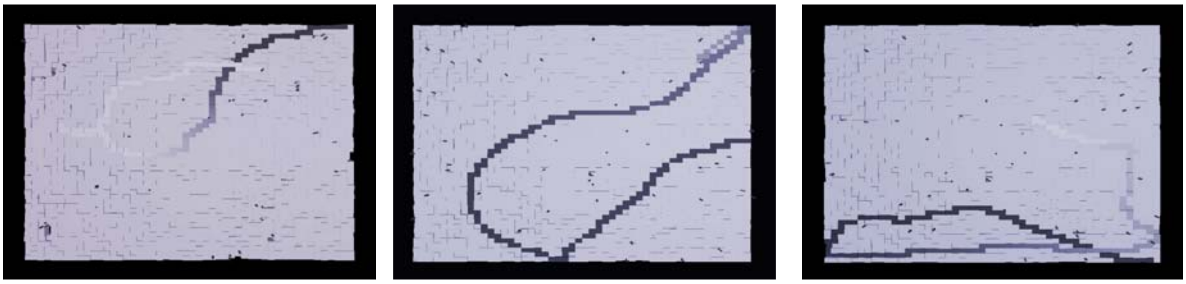

Figure 2: Each agent starts its movement from a different initial position. The blocks have been coloured lighter the more recently the agent has moved through them.

The following process determines each agent's movement, where turn step is a variable that defines the number of steps the agent takes while turning:

Loop
- If the *turn steps* counter is 0 and the *movement steps* counter is 10 then
  - set turn step counter to 1
  - set the *turn angle* to between –0.1 to 0.1 radians
- Otherwise, if the *turn step* counter is greater than 0, then
  - increment the *turn steps* counter by 1
  - turn by the *turn angle*
  - If the turn steps counter is more than 5, then
    - set the *turn steps* counter to 0
    - set the *turn angle* to 0.
  - End if
- End if
- Move forward with random speed.
- Increment the *movement steps* counter by 1

End loop

Movement is restricted within the grid. Every time an agent reaches the edges, it turns left or right quite rapidly according to the previous direction of movement. This process results to agents' interaction with different parts of the environment each time. This is demonstrated in figure 2, which shows the path of three different agents as it was recorded during our experimentation.

If the parameters "height difference" and "maximum depth" are given small values, then the environments' final form is uniformly shaped. At this point we should clarify the term *form*. It refers to the environment's shape at different points in time, while *final form* is the environment's shape at the end of the interaction agents-environment. This interaction terminates when the height difference between blocks prohibits agents' movement towards any direction. In our experimentation with small values given to previously mentioned parameters, we observe that the agents interact with all the blocks of the environment and not with specific parts of it that would result to the generation of an environment with peaks and valleys. The evenly shaped final form can be attributed to the local character of the interaction: each agent locally modifies the environment by translating one block every time while the other agents respond to the new environment at a later time.

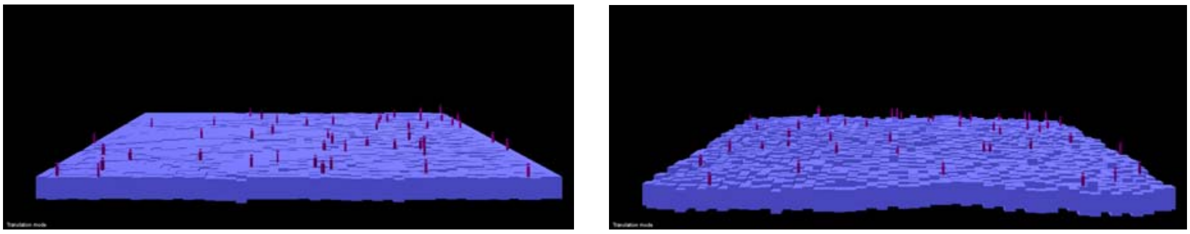

Figure 3: The environment's modification after X time steps. Two states of the environment at different points in time.

Taken it a step further, we expand agents' interaction to a neighbourhood of blocks instead of only one. This results to a smoother, plastic form of the environment (figure 4). Although the interaction can still be considered local because changes affect only one part of the environment and not the whole, it is indicated that its form can be manipulated and by extending the interaction the whole environment can be affected by one agent's action.

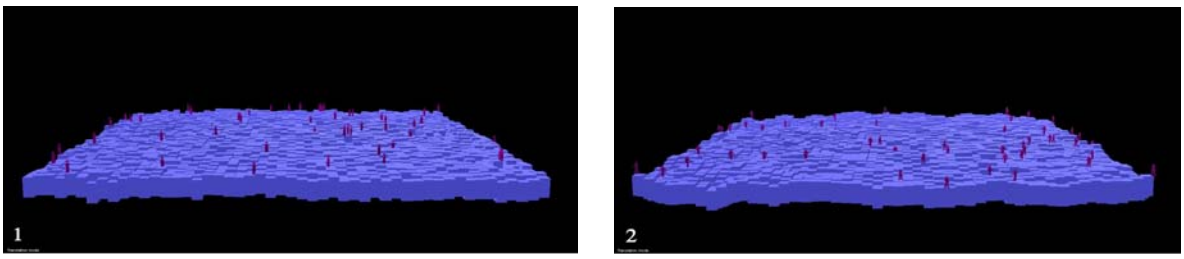

Figure 4: Experimenting with plasticity: (a) one block moved as the agent walks over it, (b) blocks within the neighbourhood are deformed as the agent moves near them.

In the above experiments, when the interaction agents-environment terminates an interesting behavioural pattern rises: the agents get trapped in a continuous circular movement on a block either as individuals or in groups, as shown in figure 5. When they form a group, they create holes made by more than one sunken blocks.

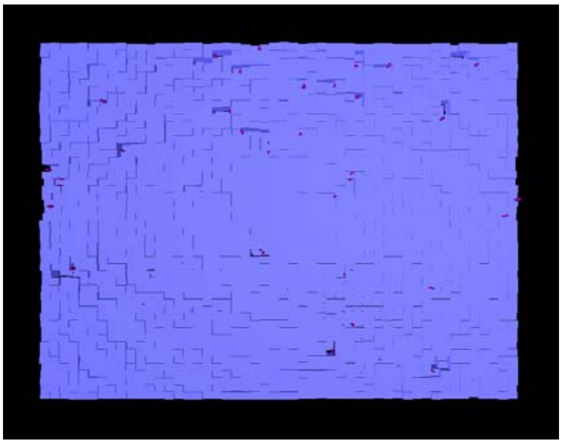
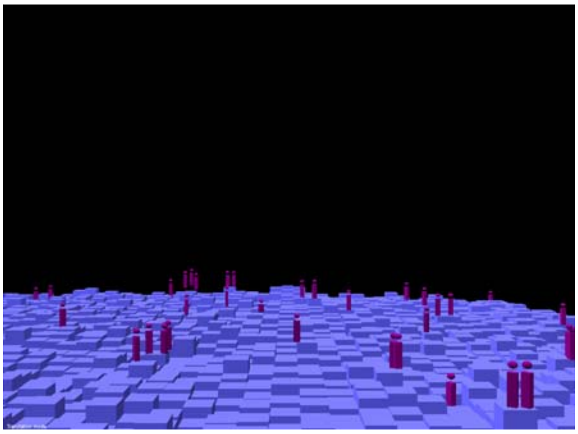

Figure 5: (a) Top view and (b) perspective view of the system when agents become trapped due to block height differences.

When large values are given to the parameters “height difference” and “maximum depth”, the agents are able to interact continuously with the environment and move towards any direction without limitations. We can consider the interaction non-constrained, since it can be infinite. This constant unlimited interaction gives rise to a curved form. This form is the outcome of agents’ movement towards the edges and corners of the grid and interaction with these parts at bigger extent than the rest of the environment. The agents’ movement in the environment is forward but limited within the grid, meaning that all agents have to turn when they reach the marginal blocks. Each agent does not necessarily interact with all the blocks of the environment. Since the number of the marginal blocks is less that this of the blocks that constitute the rest of the environment and given that more agents pass through them, they modify the marginal blocks more times than the central ones.

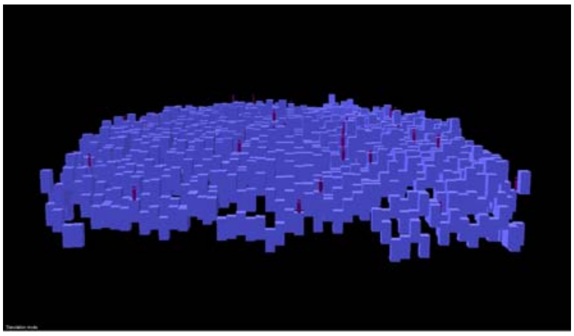
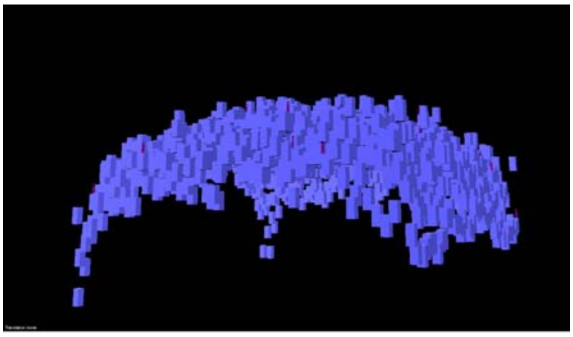

Figure 6: Curved form: two states of the environment in a different moment in time, when large values are given to the parameters “height difference” and “maximum depth”.

Our experimentation with the system showed that the height difference between the blocks and the maximum depth a block can reach are mainly the parameters –part of environment’s internal rules- that determine the extent of interaction and its duration. The agents select the direction of their movement, but it is the environment that either allows or prevents this movement that in turn brings about the changes that will occur in it. The bigger the height difference the longer the agents interact with the environment and manipulate it, resulting to more interesting forms.

3.3 Experimenting with vision

So far we have concentrated on the interaction between agents and their environment based on random movement generated by a few simple rules. Considering that our agents represent pedestrians and their movement is based on vision, in this section we present our experimentation with vision and its effect on agents' interaction with the environment.

Taking into consideration Hillier's theory of natural movement [16], we apply agents that decide on which direction to go based on the length of line of sight from their current position. They have the ability to select one out of three possible directions of movement, while their field of view is 170º. Initially, the agents select three different probable directions of movement within this field. They add the lengths of the three lines of sight of each direction and select randomly a number within that range (from 0 to sum). According to that number's fluctuation, the agents take three steps towards the corresponding direction. When the agents come too close to an obstacle or another agent, since they have the ability to see it, they turn rapidly to avoid it and select a different direction of movement.

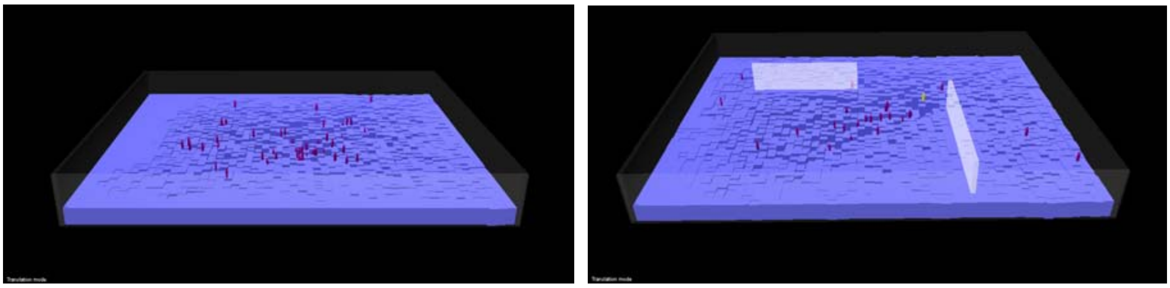

Figure 7: The longest line of sight leads agents to the central part of the environment, while the centrality is determined by configuration and availability of free space.

The agents with vision mainly move in central areas of the environment and interact with that particular part of it, because this is where the longest line of sight leads them. The centrality of an area in the environment is determined by configuration and availability of free space. For instance, if there are no obstacles in the environment, all agents concentrate exactly in the middle of the environment, while in a model with two internal walls they concentrate on the centre of the area demarcated by those two obstacles. This observation is supported by figure 7. The agents' constant interaction with the same part of the environment results to the modification of that part, giving rise to a curved form, a whirl that is shown in the following figure.

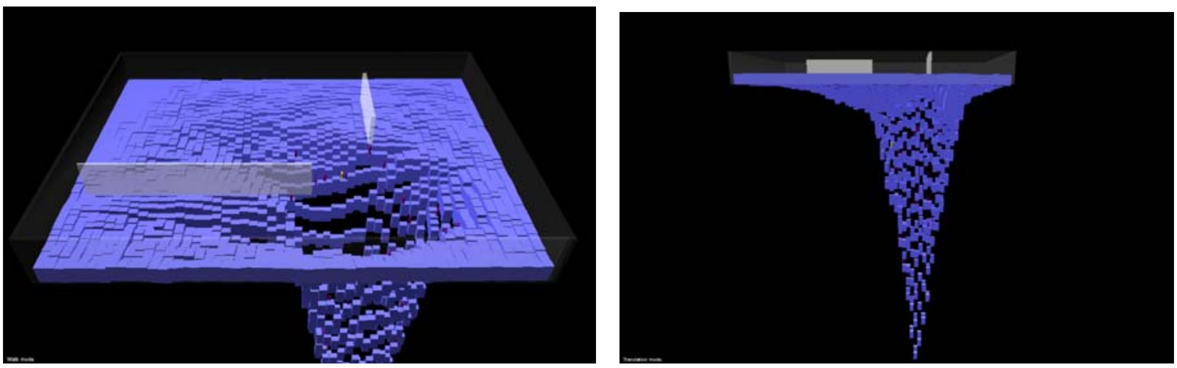

Figure 8: The result of infinite interaction between visual agents and environment.

This experiment indicates that vision and configuration can affect environments' form. Thinking of pedestrians and their actions in combination with configuration, a few questions arise: how would the environments' form be affected if the system were embodied in an actual environment? Can surroundings contribute to form? In order to explore those possibilities, we apply the system in an actual built environment, shown in figure 9. A site, Armada Way, in the city of Plymouth was selected. This choice is due to the fact that the site is at the heart of the commercial city centre and constitutes a junction of pedestrians' movement.

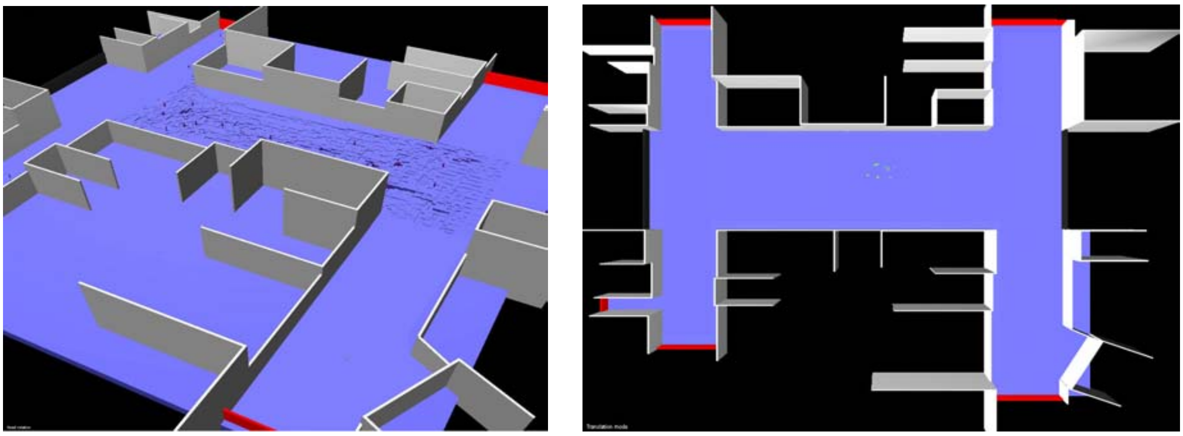

Figure 9: The agent-based system embodied in a real built environment. (a) Initially the grid was covering the whole site. (b) For simplicity, it was decide to limit it to the central rectangular area.

Although initially the agents move throughout the site, they end up in the centre of it and mainly interact with that part of the environment resulting to a conical form. They exhibit behaviour similar to the one in the previous experiment with vision, before the model was applied to the real site. In both cases, the result of this behaviour is a curved, conical shape. Since it is repeated we can talk of a pattern, the whirl pattern.

The system's application to the real site shows that there is an indirect correlation between the surroundings and the environment's form: what the agents can see guides their movement that in turn affects the interaction –since movement is the medium through which interaction is realized in time- resulting to a particular form. That form emerged because of specific conditions and interactions that took place at the particular moment the whole process occurred.

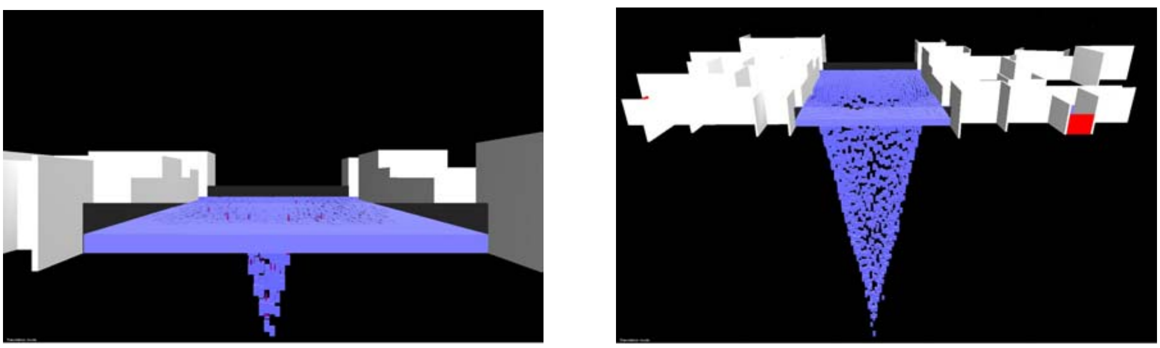

Figure 10: Whirl pattern as the outcome of agents' behaviour based on vision.

4. Conclusions

So far we have concentrated on the interaction between agents –representing pedestrians– and their environment experimenting with parameters that affect that interaction and ignored the subject matter that lies behind. Looking at the process and the outcome from that perspective, we can say that the environment evolves in time through movement. Movement is the external force acting on the environment that constitutes the medium through which the interaction is realized. Referring to the result of that interaction, we could use the landscape metaphor to characterise the environment's final form. Looking back to the experiments and emerging forms, in most cases despite randomness or diversity in values given to parameters, the result is an evenly shaped form, a uniform landscape using the above metaphor. Taking into consideration Waddington's epigenetic landscape we should attribute this outcome to local character of interaction. Any change in the environment caused by agents' movement is not distributed smoothly in the whole surface, but its influence is locally related to a block. A change evenly distributed across the environment would result to an undulating form, as it was indicated by the experiment shown in figure 4. In a way this interaction could still be considered local because changes affect only a part of the environment not the whole, however it indicates the difference in the outcome.

Looking back to the nature of interaction between agents and their environment, we see that because of movement the environment's shape changes at every point in time: each agent locally modifies the environment giving rise to a particular form, while the other agents respond to the new environment and transform it at a later time. It is an environment that constantly evolves along with its form. As far as agents are concerned there is an indirect interaction between them, indicating that the phenomenon of stigmergy is possible to take place among interactions with human analogy. It becomes obvious that this is a process totally connected to time and cannot be realized otherwise.

Taking into consideration the evolving environment and the changes that occur to it as structural changes lead us to our hypothesis. It has been hypothesised that the recurrent interaction between agents and environment can lead to a structural coupling between those elements. It means that every time a change occurs in each one of them, as an expression of its own structural dynamics, it triggers changes to the other one. Our results so far imply that it is possible for the agent-based system to evolve structural coupling but in its current state we cannot argue that the hypothesis is fully verified. The agents' movement on the environment brings about the changes that occur on it, but it is the environment's internal rules that determine the nature and extent of change. Given that the agent-based system has succeeded on that we can speculate that it is possible for the system to be developed to verify its hypothesis, as long as the interactions between agents are developed to result to adaptive behaviour.

In our attempt to explore the interaction between pedestrians and their environment and the implied idea of external forces' involvement in the generation of form, we followed a process of combining ideas and theories from diverse fields of knowledge: architecture and biology. Considering the process and the outcome along with each field's contribution, we could say that if biology has something to teach us it is that processes of temporal formation produce organisations of a far higher complexity and sophistication than instantaneous ideas. It provides us mechanisms that explain phenomena, emergent or not, and not a formalised manner of how these phenomena might occur.

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[15] The agent checks the height difference between the block it is standing on at the time and the block it intends to step onto the next moment. If the height difference is smaller than the given value the agent continues moving towards that direction, otherwise it turns gradually to select another direction of movement that the height difference allows it to follow.

[16] That theory shows that the majority of the human pedestrian movement occurs along lines of sight. It considers the axial line as the guiding mechanism of human pedestrian behaviour. Turner and Penn, op. cit. p.476

Pseudo-urban automatic pattern generation

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Abstract

Notre but dans ce travail est de rechercher et d'expérimenter des méthodes de production automatique de morphologies urbaines ou architecturales. Nous avons jusqu'ici implémenté et fait converger des dispositifs s'appuyant sur une heuristique couplant un moteur de production de séquences pseudo-aléatoires avec un formalisme graphtal, de type L-System (Lindenmayer System). L'objectif étant dans un premier temps de produire simplement et "à moindres frais" des environnements géometriques texturés visitables par le biais de technologies de visualisation 3D temps réel. Ce modèle de croissance, qui a déjà donné des résultats intéressants pourra être dans un deuxième temps perfectionné par l'utilisation de systèmes logiciels à comportement émergent, validé par des appréciations perceptives et contraint par des informations d'ordre topographique ou des règles de production urbanistiques ou architecturales. Ceci pourra, par exemple dans le domaine de l'archéologie urbaine et dans un contexte historique donné, permettre de produire rapidement un support d'hypotèses de restitution en présence de données fragmentaires.

In questo nostro lavoro di ricerca ci poniamo come obiettivo di sperimentare metodi di generazione automatica di morfologie urbane e architettoniche. Abbiamo finora sviluppato e fatto convergere taluni dispositivi, come seriazioni pseudo-random e formalismi graftali, o L-sistemi (Lindemayer system) al fine di produrre rapidamente spazi tridimensionali immersivi. Questi modelli di crescita hanno già dato nel nostro campo risultati interessanti. I successivi sviluppi, traendo spunto da inputs topografici e/o ambientali, dovrebbero promuovere la ricerca nel campo del calcolo emergente. Questa ricerca trova una valida applicazione nell'ambito della restituzione archeologica a grande scala, dando il modo ad esempio di produrre "rapidamente" ipotetici ma plausibili tessuti urbani storicamente contestualizzati.

This research task aims to experiment automatic generative methods able to produce architectural and urban 3D-models. At this time, some interesting applicative results, rising from pseudo-random and l-system formalisms, came to generate complex and rather realistic immersive environments. Next step could be achieved by mixing those techniques to emerging calculus, dealing whith topographic or environmental constraints. As a matter of fact, future developments will aim to contribute to archeological or historical restitution, quickly providing credible 3D environments in a given historical context.

1. Introduction

Since the end of the 70's, the "fractality" of our environment raised as an evidence, pointing some peculiar aspects of everyday phenomena. Some micro and macro-scopic internal-arrangement principles appear to be similar or even auto-similar, leading the reasoning through general explanatory theories. Physicians and biologists regularly discover fractal processes through natural morphogeneses such as cristalline structures or stellar distribution. Human creations also seem to be ruled by fractal fundamentals and since 15 years, the "fractality measure" of some human artefacts can be somehow achieved.

Fractal investigation through urban patterns mainly focused on two subsequential aspects : the direct analysis of spatial organisation, and thus the formalization of self-generating geometrical structures. The growth of urban models is at this time fulfilled either by time-based spatial simulators or by simple static generators. Spatial simulators are usually based on simple "life-game" (cellular automata) devices or even by "diffusion limited aggregation" formalisms (DLA). In this paper, we will mainly focus on some generative techniques involved in 2D and 3D automatic builders.

2. Research task context

The mainframe of this research task consists in real-time rendering of huge 3D databases. Different aspects of this goal have already been explored, considering from the top that rendering techniques should be optimal for a given applicative context. Therefore, the main aspect of MAP-aria participation in this project consists in building plausible urban structures related to some given historical or archeological context.

Early stages of our investigation pointed the discontinuous properties of growth phenomena. In other words we barely believed in the existence of a possible continous morphological development model, according to the evidence of micro and macro-scopic observable morphological differences on one hand and through bidimensional and threedimensional topological discontinuities on the other. In other words, we focused some "scale-based formalisms", related to specific urban scale-types, as listed in the following section:

3. Applications

The description of the following formalisms is broadly summarized. Further refinement on geometrical models, architectural primitives and morphological break-down are under development...

3.1 Multi-scale pattern generator

A "top of the heap" wide range concentric propagator, whose aim is to distribute, filter and drop geometric locators above a given terrain mesh.

The deal is here to develop a "general land-scaled model", mostly a variant of the L-system model depicted below. The initial distribution of locators basically follows a concentric distribution. Their final positioning can be meanwhile modified by some disruptive factor, mostly depending on simple angular non-overlapping constraints. The graph below shows three different steps of the computation : locators displacement, neighbourhood tracking and plot drawing.

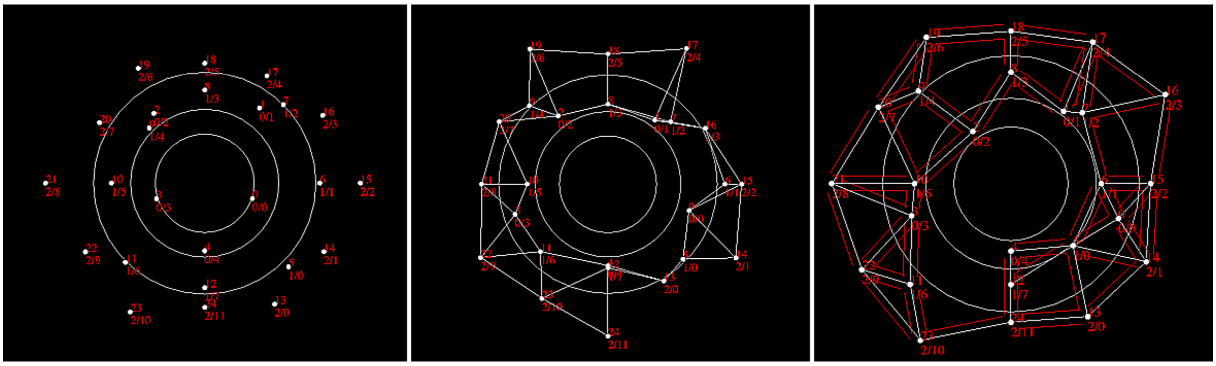

Figure 1. Deployment of a 2D geometric model.

A local geometric transformation transforms the initial structure to a position-related “constructible zone“, starting from two initial input variables, named here d‘ and d’’ . At the moment, inevitable angular occlusions occur whith sharp and wide angles. This drawback should meanwhile be solved in a very next release of the applet.

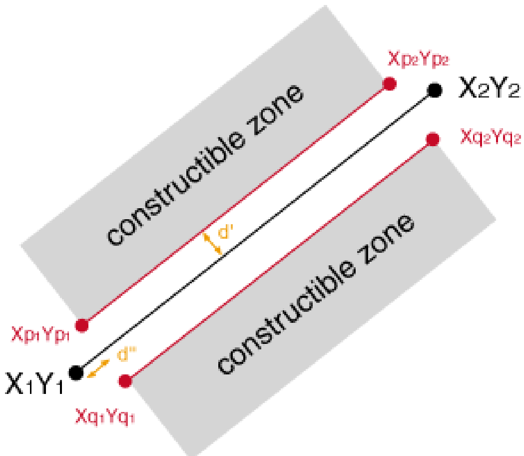

Figure 2. Geometric deduction of “constructible zones“.

Extracting the *n* closest neighbours and drawing the respective bijective connexions leads the entire process, and we can finally hybrid this bidimensional mesh to allocation rules and topopgraphic constraints, to produce the models shown on the figures below : the skeleton and the final rendering.

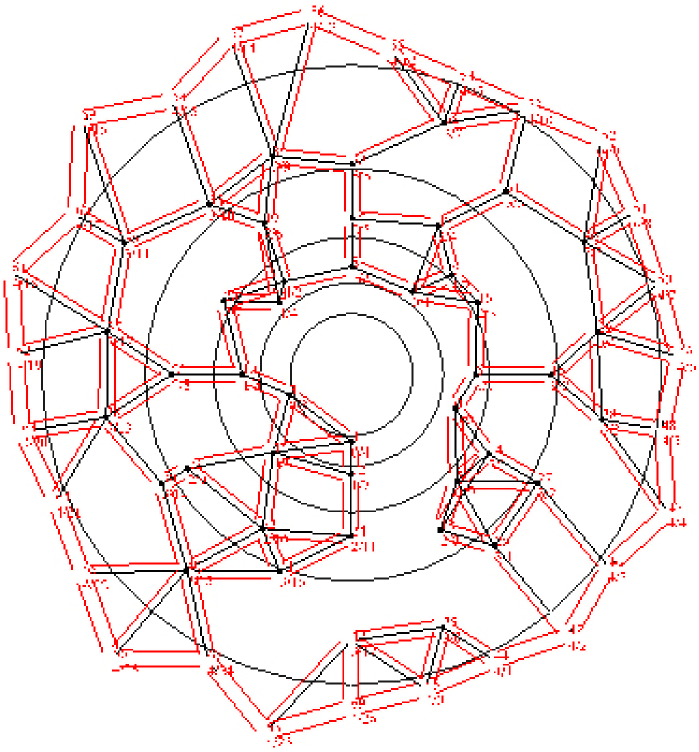

Figure 3. The geometric skeleton...

Figure 4. …and it's 3D expression.

In this example, only one architectural primitive is distributed over the map ; a “hull – filling “ generator (shortly described below) could be implemented to create a more realistic perceptive variety.

3.2 Graphtal or L-system generator

Graphtal or L-system, applied to local building and block propagation.

The L-System, or Graphtal, starts from a simple recursive substitution mechanism. This rules-based generator, described in the late 60’s by A. Lindenmayer [1], can quickly provide complex geometric developments. It’s charachteristic deal whith simple substitution rules, recursively applyed to a sprout, as shown below :

All we need to start is an alphabet, listed hereby : 0,1,[,]

In this example, 0 and 1 occurrences will “produce geometry“ while [and] will provide a simple affine transformation (rotation and/or translation). We can now describe simple substitution rules, applied to alphabetic elements :

0 : 1[0]1[0]0   **1** : 11   **[** : [**]** :]

If we recursively apply those substitution rules to an initial sprout (applied from the top to the rule of letter “0“) we obtain :

11 [1[0]1[0]0] 11 [1[0]1[0]0]1[0]1[0]0

Two “generations“ or recursive steps later we obtain :

11 11 11 11 [11 11 [11 [1[0]1[0]0] 11 [1[0]1[0]0] 1[0]1[0]0] 1111 [11 [1[0]1[0]0] 11 [1[0]1[0]0]1[0]1[0]0] 11[1[0]1[0]0] 11 [1[0]1[0]0] 1[0]1[0]0] 11 11 11 11 [11 11 [11 [1[0]1[0]0] 11 [1[0]1[0]0] 1[0]1[0]0] 1111 [11 [1[0]1[0]0] 11 [1[0]1[0]0]1[0]1[0]0] 11 [1[0]1[0]0] 11 [1[0]1[0]0] 1[0]1[0]0] 11 11 [11 [1[0]1[0]0] 11 [1[0]1[0]0] 1[0]1[0]0] 11 11 [11 [1[0]1[0]0] 11 [1[0]1[0]0] 1[0]1[0]0] 11[1[0]1[0]0] 11 [1[0]1[0]0] 1[0]1[0]0

The “trick“ consists here in replacing the brackets by specific 3D operations – typically affine transformations, such as rotations or translations - and the “0“ and “1“ occurrences by 3D pre-defined objects. We notice how the transformations and object creations are invoked in the following source code (obviously part of the main program, implemented within a “switch“ JAVA object) The resulting output sourcecode is VRML 97, mimed with a CosmoPlayer© plug-in.

```
case '1'    :

      devX=devX+0.5/propag;

writeln(' Transform \{ rotation 0 1 0 '+-k+' translation '+devX+' 0 0 children \[ Transform \{ rotation 0 1 0 '+k+' children Shape \{ appearance Appearance \{ material Material \{ diffuseColor 1 1 1  emissiveColor 0.3 0.3 0.3 \}\} geometry Extrusion \{convex FALSE crossSection \[-0.5 -0.5 , -0.5 0.5 , 0.5 0.5 , 0.5 -0.5 , -0.5 -0.5 \] spine \[ 0 '+alt+' 0 , 0 0.1 0 , 0 0.1 0 , 0 0.15 0 , 0 0.15 0 , 0 0.2 0 , 0 0.2 0\]  scale \[ 1.5 1.5 , 1.4 1.4 , 1.3 1.3 , 1.3 1.3 , 1.25 1.25 , 1.25 1.25 , 1.2 1.2 \] \}\}\}\]\}');

      nbobj=nbobj+1;
```

```
      break



case '0'    :

      devY=devY+0.5/propag;

writeln(' Transform \{ rotation 0 1 0 '+-k+' translation 0 0 '+devY+' children \[ Transform \{ rotation 0 1 0 '+k+' children Shape \{ appearance Appearance \{ material Material \{ diffuseColor 1 1 1  emissiveColor 0.3 0.3 0.3 \}\} geometry Extrusion \{convex FALSE crossSection \[-0.5 -0.5 , -0.5 0.5 , 0.5 0.5 , 0.5 -0.5 , -0.5 -0.5 \] spine \[ 0 '+alt+' 0 , 0 0.1 0 , 0 0.1 0 , 0 0.7 0 , 0 0.8 0 , 0 0.8 0 , 0 0.9 0\]  scale \[ 1.5 1.5 , 1.4 1.4 , 1 1 , 1 1 , 1 1 , 1.05 1.05 , 1.05 1.05 \]\}\}\}\]\}');

      nbobj=nbobj+1;

      break



case '['    :



      ouvcrochet=ouvcrochet+1;

      alt=alt-0.2;



writeln(' Transform \{ rotation 0 1 0 '+-k+'   translation  '+devX+'  0.2 '+devY+'  children \[ Transform \{ rotation 0 1 0 0 children \[');

writeln(' Transform \{ rotation 0 1 0 '+k+' translation '+devX+' 0 '+devY+' children \[ Transform \{ rotation 0 1 0 '+k+' children Shape \{ appearance Appearance \{ material Material \{ diffuseColor 1 1 1  emissiveColor 0.3 0.3 0.3 \}\} geometry Extrusion \{convex FALSE crossSection \[-0.5 -0.5 , -0.5 0.5 , 0.5 0.5 , 0.5 -0.5 , -0.5 -0.5 \] spine \[ 0 '+alt+' 0 , 0 0.45 0 , 0 0.55 0 \] scale \[ 1 1 , 1 1 , 1.05 1.05 \]\}\}\}\]\}');



      nbobj=nbobj+1;

      break



case ']'    :



writeln(' Transform \{ rotation 0 1 0 '+-k+' translation '+devX+' 0 '+devY+' children \[ Transform \{ rotation 0 1 0 '+-k+' children Shape \{ appearance Appearance \{ material Material \{ diffuseColor 1 1 1 emissiveColor 0.3 0.3 0.3  \}\} geometry Extrusion \{convex FALSE crossSection \[-0.5 -0.5 , -0.5 0.5 , 0.5 0.5 , 0.5 -0.5 , -0.5 -0.5 \] spine \[ 0 '+alt+' 0 , 0 0.05 0 , 0 0.05 0 , 0 0.4 0 , 0 0.4 0 , 0 0.5 0 \] scale \[ 1.2 1.2 , 1 1 , .95 .95 , .95 .95 , 1 1 , 1 1\] \}\}\}\]\}');

writeln(' \]\}\]\}');

      ouvcrochet=ouvcrochet-1;
```

```
alt=alt+0.2;

nbobj=nbobj+1;

break
```

Depending on initial rules, such a model can quickly “run out of control“ and generate huge 3D databases. It’s specific initial generative inputs are the only condition for the whole evolution process – which is meanwhile eminently determinist ; nevertheless, geometry partial overlaps are frequent and due to concatenated affine transformations previously described. Hereby we show a four-steps generated VRML model, made of solely 2 architectural primitives. Some extra visual artefact is provided by the height change of the objects, depending on their distance to the first geometric settlement.

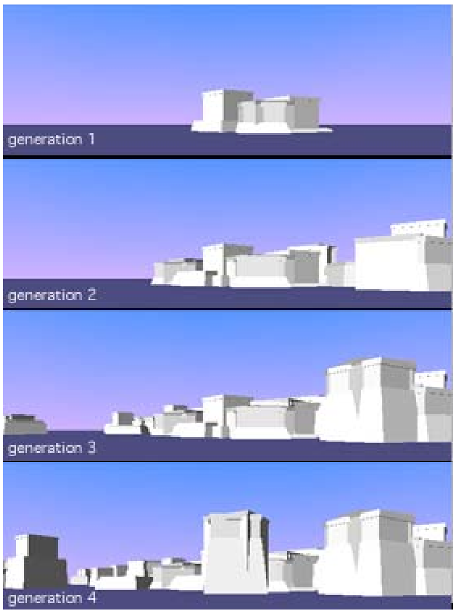

Figure 5. A L-System-based growth engine.

Most of these generative models are developed whithin a web browser interface : a javascript code which dinamically generates a VRML source displayed by a CosmoPlayer plugin. We are studying by now other geometrical algorithms, in order to constrain these L-system, such as Voronoï diagrams or Delaunay triangulations.

3.3 Random or pseudo-random “hull-filler“

Random or pseudo-random “hull-filling“ generators for single-building construction.

The “hull-filling“ model offers by itself rather interesting investigative perspectives : in this model the specific positioning of architectural types or sub-types could be guided by a prior analysis that tends to break down or disassemble some historically-contexted architectural types by a morphological factorization. The process is obvously reversible and could be achieved by a rules-based grammar. The amazing Palladio 1.0 Macintosh© Hypercard Stack [2] is a noteworthy example of such a morphological synthesis. We also must here quote the scientific goal of the research team “Laboratoire d’Analyse des Formes“ from the architecture school of Lyon that leads somehow this specific aspect of this research task.[3] Their aim is to identify major stylistics guidelines from distinct architectural families, dispatching them through pre-identified morphologic, functional, architectonic and compositional occurrences [4]. A similar search will soon commence, leaning on Claude-Nicolas Ledoux architectural production, whose factorizable characteristics appear as an evidence.

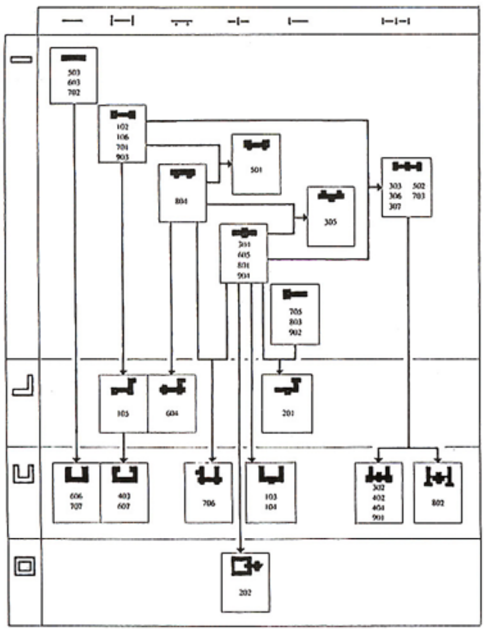

Figure 6. A graph-based morphological parser.

Courtesy of "Laboratoire d'Analyse des Formes"

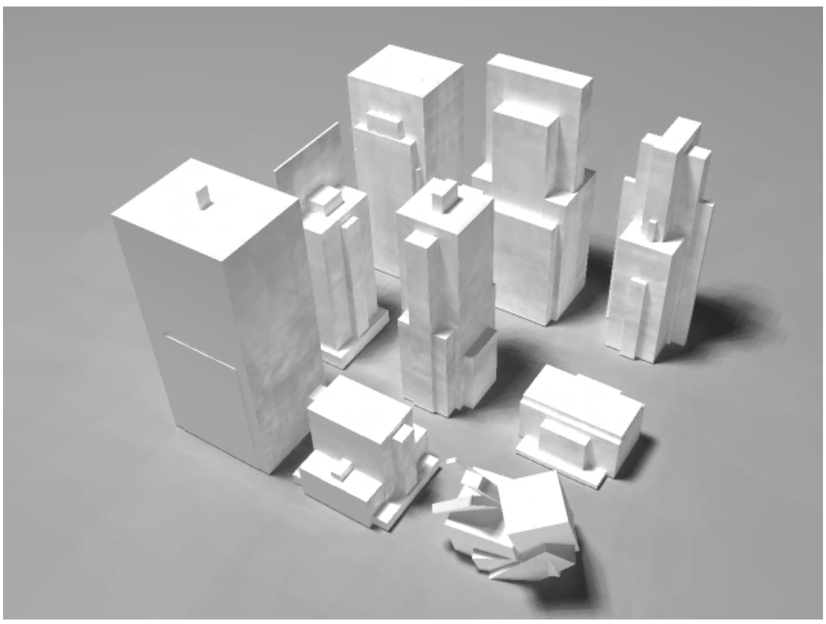

Figure 7. Some “hull-filled“ objects.

At the moment, this complex formalism is barely drafted; it is therefore interesting to point out the relevant difference of the “ugly duckling“ bottom right object, that descends from the same construction formalism but differs from 1 single input attribute.

3.4 Random 2D – 3D generators

Random or pseudo-random simple pattern generators applied to facades, according to buildings height or local floors indentations.

This very first applicative experiment was only acquired to test some early combinational conjectures. Some 3D “hull-filled“ objects are textured whith simple combinational patterns ensuring somehow an intrinsic global coherence in order to avoid 2D and 3D possible mismatch. This could be achieved by establishing for instance a common spatial framework, arbitrarly bounded here by 2,5 meters-sided cubes. As shown in the picture below, the intrinsic coherence of the texture itself depends on the pertinence of single texture patches positioning, known as inner, top, left, right and bottom occurrences : on the illustration, the gray-filled board zone invoke specific ledge-type instances as the inner white zones use generic tiles. Right underneath, some texture patches that come whith the 2D library and below, two facade variants.

These examples are here intended as “ironic standalone designs“ : the (im)pertinence of these random objects is obvious. Meanwhile, if coupled whith accurately-sized 3D objects, the visual impression could be effective, as shown on Figure 6 .

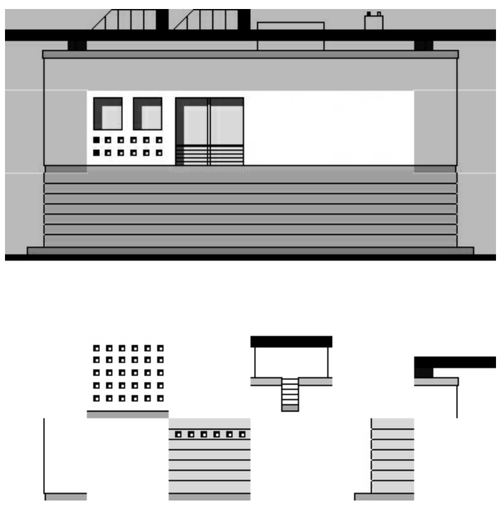

Figure 8. The automatic facade builder :o)

Figure 9. Some “automatic“ facades.

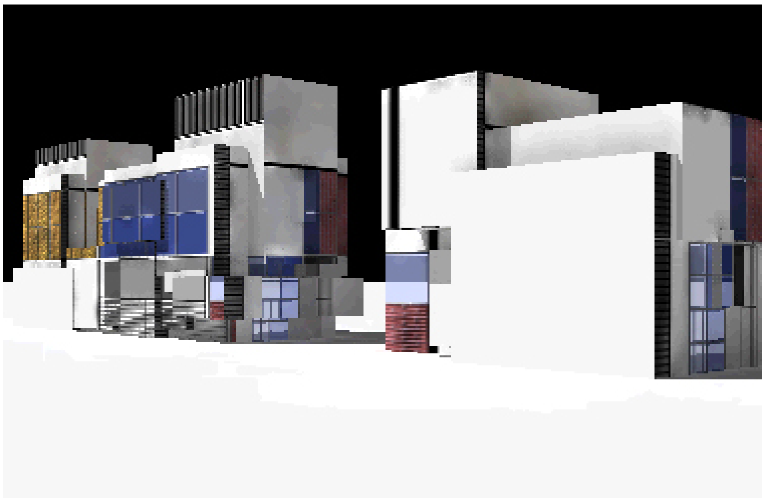

Figure 10. Applying and rendering colored tiles on specific 3D objects.

4. Conclusion

Virtual reality hardware and software costs and means are still relevant today. Trying to partially solve this peculiar aspect of leading 3D rendering techniques is part of the regional DEREVE project, whose aim is to build a convergent know-how, trying to extend hardware and software intrinsec performances through methodological and algorithmic applications, in terms of modeling and rendering. As a matter of fact, the specific involvement of the “MAP-aria“ lab in this research task deals whith 3D scenes building, leaning on his specific architectonic culture and virtual reality previous experimentations.

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5.1 Related webgraphy

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http://www.ctpm.uq.edu.au/virtualplants/ipivp.html

http://www.cpsc.ucalgary.ca/projects/bmv/software.html http://www.cs.hope.edu/~alganim/ccaa/algo.html

www.casa.ucl.ac.uk

Projeto Missões, Computação Gráfica Multimídia da Reconstituição Computadorizada da Redução de São Miguel Arcanjo no Rio Grande do Sul - Brasil

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Abstract

The Design Missions - Graphical Computation, recoups in a graphical and digital the pictures of the Church and the Reduction of *São Miguel Arcanjo, RS, Brasil*, allowing to the public a virtual stroll through the set at the time of its foundation in 1687. Initiate in 1990, the design refers the appropriation and implementation of the new computational technologies. The 3D model allows the dynamic visualization of the set, through aerial sights and walkthrough animations into the main streets and the inward of the central ship of the church.
For the generation of the model, it was followed the principles of the architectural composition to decompose the parts, to be shaped, defining the architectural and composition elements. This COMPACT DISC, is one of the some medias of the Design Missions - Graphical Computation. In this proposal, the music was developed especially for the COMPACT DISC, looks for to reflect the poetical aspect of the interaction between light, shadow, of the inwards and exteriors, attenuating the technology of a virtual environment. In the integration between the art and the technology its recovered virtually, the poetical way, the memory of one of the icons of the identity of the Rio Grande do Sul, with the objective to keep alive, for the new generations, a patrimony that practically in ruins would have the souvenir of its lost real picture in the time.

The Work

In 1990, a celebrated joint with Iphan[1], of Rio Grande do Sul aimed on making a computerized reconstruction of Reduction São Miguel Arcanjo in the state of Rio Grande do Sul, Brazil, guided us on a productive way, conducting us (until this moment) through computers technology applications and its interface with theory, concepts and way of thinking that arouses Architecture as knowledge subject.
This work, that was further widespread at that time for being unheard reappear now, once again, with another conceptual and creative structure: as a multimedia product. This CDROM, inserted in the Mission's book that has been edited by Universidade do Vale do Rio dos Sinos begin to assume the hole to spread the architectural Heritage, not only among academics or

[1] Instituto de Patrimonio Histórico e Artístico Nacional

specialists as it has been happening until now, but people in general.
The text below refers exclusively the peculiarities of the multimedia products conception, searching for a new way to express these ideas, potencializing new support possibilities.

Conceptual Premises

The conceptual base or line of thinking that prevailed intended to arise to other human sensibility levels through artistic, literary and musical resorts utilization, emphasizing its aesthetic effects of visual and hearing impacts.
Adopting as reference some concepts that come from an architectural reflection and making them implicit through images and animations production, we try to induce the observer to feel spaces not just as its geometrical, formal or constructive appropriation, but arousing him into a high and joy level of sensible perception, thereby using a context of effects and tricks. Though this context is underlying to the usual media, is part of the architectural critics and thoughts.[6] It means that, fundamentally, the CDROM works at the sensations and emotions plan. In order to achieve that, it resumes Giambattista Piranesi ideas from the "expressive fantasies": "The habit of studying graphically the old architecture we have got, finds in Piranesi an interpretation itself. Its images never meant to be an objective view of the reality, however reinforced the huge view of the ruins with smaller figures than usual, insolit points of view and dramatic dark-bright."(Rocha,1998) [1]

**Figure 1 – Redução de São Miguel Arcanjo RS/Brasil –
View of the church at sunrise.
Source: Núcleo de Computação Gráfica-Unisinos**

Yet, reminds Boulee, whose book *Architeture: Essais sur l´art* declares himself the creator of the shadows and darkness architecture.(Rocha,1998)
The reflection of the architectural space conception was one of the important premises in order to elaborate the video and the progress. As the main dimension, the architectural space results from the composition of these spaces, organized one by one through the most important ways. Le Corbusier with him *promenade* architectural and the *beaux-arts* with la *marche* can be quote. In our case, building the way, the light, color, texture in a sequence and transforming it, introducing special effects is the main line to the CD conception established aim since the beginning of the process means to stimulate the observer

sensibility.(Rocha,1998)[2]

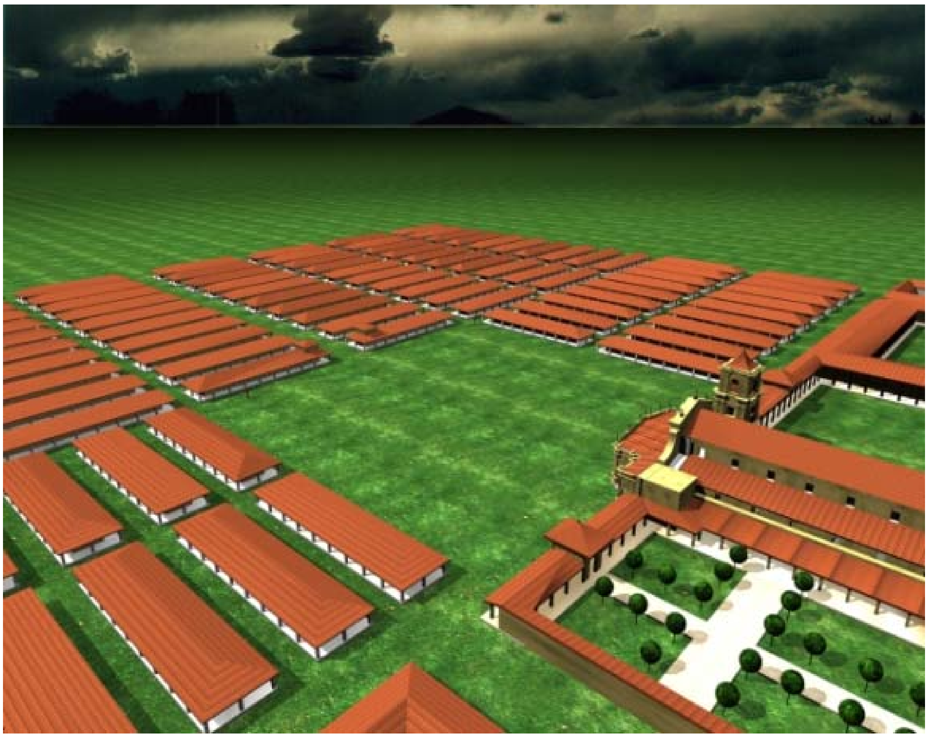


Figure 2 - Redução de São Miguel Arcanjo - RS/Brasil – View of the cemetery Source: Núcleo de Computação Gráfica- Unisinos

Script

The product had a conception based on a contemporary technology link, using a narrative based on some elements of the aristhotelic speech – sequential and linear – though in a hypertext and hypermedia context. The soundtrack conception, since the beginning, and its *prologue-episode-epilogue* structure, has joined contextualized musical elements.
The music was created especially for what has been being watched and has its aim based on a visual language sonorous punctuation. The main sense of all these different temporal insertions on the model, sends the speech to beyond on this same model, creating space and time appropriations that usually, don't content the pure and simple description of a virtual journey, searching for unusual journey that don't seem to follow an observer walking, but the points of view and his steering that are unsuitable with its reality.
The production of these additional elements to the model itself gives us the presence of a non-visual context that interferes on the observer comprehension.[6]

These extra-diageticals elements – the day, the night, the fields, the warmth, the cold, - though not visible, cover itself with a symmetrical importance to the diagetical objects-the model itself- with the intention of forcing the observer participation, recreating environment. It's not meant to create a realistic way, but a similar one. That is not real; though lead us to the truth. In this case the narrative doesn't have to seem real, it has to give us a real sensation.[3]

Figura 3 - Redução de São Miguel Arcanjo - RS/Brasil – The hole reduction view an unusual context of the fields Source: Núcleo de Computação Gráfica-Unisinos

Dramatic Structures

The CD´s poetics: Intently the script was Aristotelian and basically composed of a presentation of the theme in a time and space level. The narrative is sequential, inter-independent and evolutional, based on some episodes that introduce the object in an evolution way, studying its physical, conceptual and tectonic structure.
The videos autonomous structure uses the hypermedia potential in a classical way of " beginning-middle-end" and induce us to a result that consists and observer appropriation of the architectural object in different levels of the human sensibility. The hypertextuality is an alternative for the user or viewer only after a presentation that intends to sensibly him by an introduction of a fictional literature.

The Introduction

The use of an Aristotelian classic poetics propose us an historic contextual hypertext reading, with a female voice telling a Jesuit priest thought a part of Erico Verissimo`s novel *" O tempo e o vento"* such as the prologue.
After the video presented a starts to twinkle introducing the image of the church in a virtual space.

Main Menu

The user access the main menu that is composed of five modules through where the user can "surf" according him desire.

Project – That's the project historical from 1990 until 2000, in its different steps.
History - Narrated and shows images of the social, political and economical context of the Mission until the destruction, emphasizing architectural and urban characteristics.

Images – Searching, through some effects, for the fantasy of the sunrise and sunset at the mission. The images show the note place, the symmetry, the landscape, the local environment, the horizon.[3]

Videos – In this link the user choose witch sort at video to see. The videos were elaborated in away that try to show, in some cases, the underlying perceptions than the architectural character.

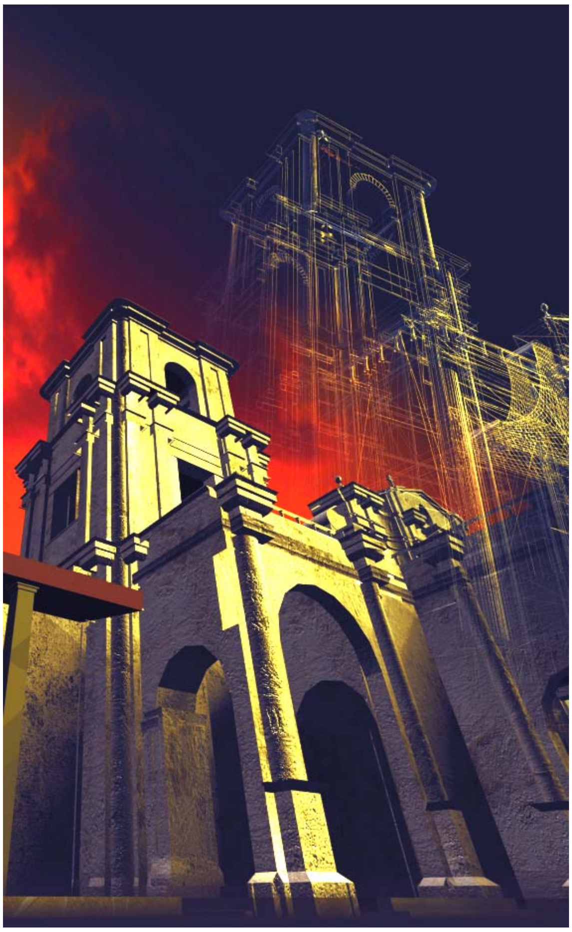
Considering that this character is the feeling evocated for the observer from the object the architectural effects such as spaces, journey, church interior; the sacramental spaces emphasized by the music, the light, shadows, dark and bright, were the bases for the rendering and animations. As an example, the camera stands to show the monumentality of the architectural object the observer considering the hole and the parts.

On the option FLOOR: the observer walks around the village in a contemplative way with light music creating expectation in each new image. The spectator scale remains the same while he is getting in and at the houses, giving a sense of the Indians "everyday life" .[4]

Figure 4 - Redução de São Miguel Arcanjo - RS/Brasil – Internal view of the priest house yards and the factory. Source: Núcleo de Computação Gráfica - Unisinos

On the option FLY the way – the observer can fly over the village, in a fantastic music grows slowly creating expectations and a sadness preparation for the " gran finale" of the sort of images that appear during the team.
The destruction, the Phoenix that was born by the ash in the computer screen. The church INTERIOR, as an architectural space allegory. The music – *Pater Noster* – contribute with the space to give the divine mod. The importance of the moment, try to give the ritualistic idea of the power of God. Emphasis on the bright-dark effects.[5]

Figura 5 - Redução de São Miguel Arcanjo - RS/Brasil – Internal view of the church. Dark-bright and light shadows effects. Source: Núcleo de Computação Gráfica- Unisinos



The team

This module that represents the CD' epilogue continues with Pater Noster, and orchestra as the musical background meaning an idea of perennial and growing environment and addition to the images give the user an idea of continuity.[6]
As all the theatrical shows, in a meaning analogy, while the music goes on, the modules as the actors leave the scene, coming back for the applauses.

Figura 6 - Redução de São Miguel Arcanjo - RS/ Brasil As imagens procuram atingir o observador no plano das sensações e das emoções.

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The generate method of Multi-storey Chinese Pagodas

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Abstract: As many traditional Chinese architecture, pagodas are also very mature and formal. In this paper, we try to find the rule of the shape of Multi-storey Chinese Pagodas, and try to describe the rule in logical math language. This study will help computer programmer create the model of the pagoda in parameter-driven way. We wish more scholars were interested in study traditional Chinese architecture by generate method.

Keywords: Generate, Pagoda, Chinese, Math

The introduction of Chinese pagoda

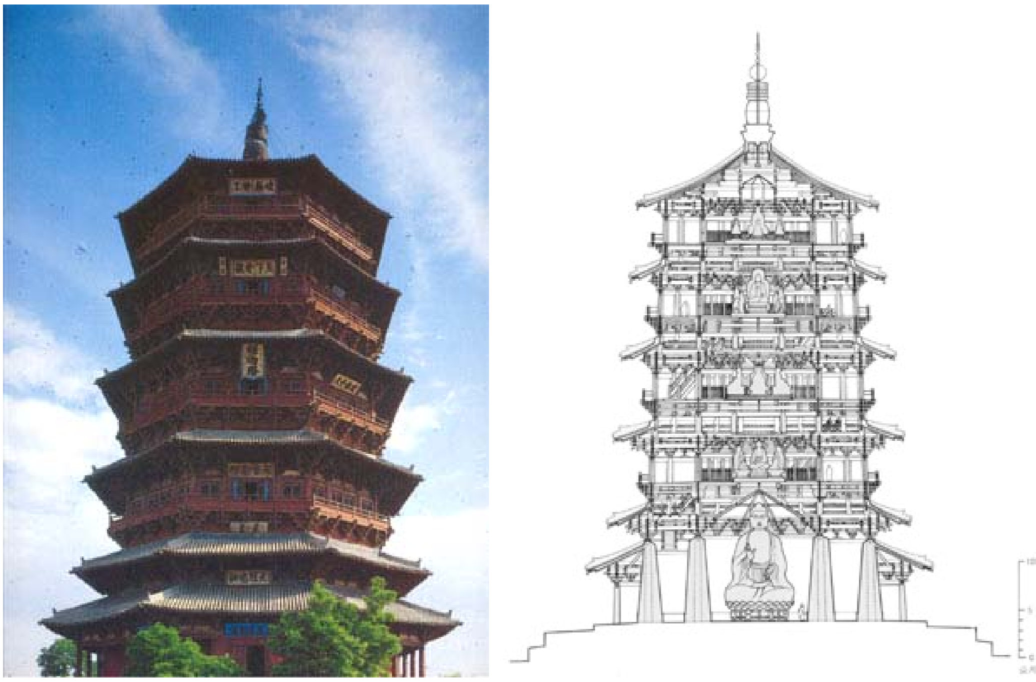
The word pagoda denotes a tower-like building constructed either of marble, stone, glazed and unglazed bricks, wood, iron or bronze. It is generally understood that the influence of the Indian Stupa was the origin of these buildings. Since a considerable intercourse between Indian and China was kept up by common Buddhist religious interests, there can be no doubt that certain types of pagodas at any rate are of Indian origin.

Figures 1: The Indian Stupa

It is not impossible that the real origin of pagodas was just a simple rectangular building with an additional storey added for effect and then perhaps more added until a tower-like shape was achieved.

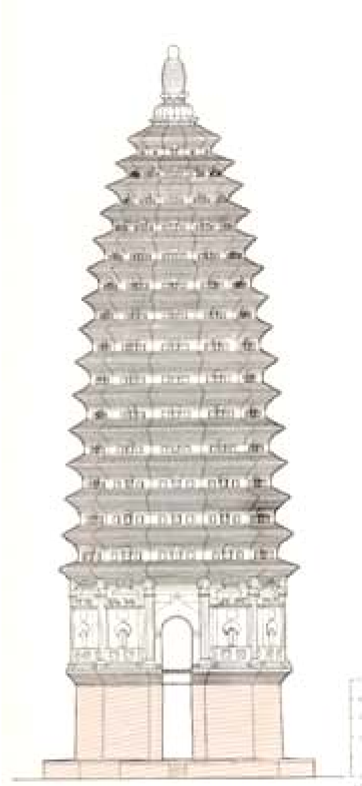
In the T'ang period (A.D.618–906) pagodas were usually simple, square structures; they later became more elaborate in shape and adornment.

Nearly all types of pagoda are now octagonal in plan, a natural evolution from the square when designing a tower. It should be noticed that pagodas always have an odd number of roofs in accordance with the Chinese theory of numbers. Each storey diminishing in which while simultaneously each order is reduced in height.
Pagoda is also the main integrating part of the Buddhist architecture, with varied styles and strong local flavours. Pagoda followed Buddhism into China around the first century, and developed into pavilion-like pagoda on which one can view scenery after immediate combination with traditional Chinese architecture.
Most Chinese pagodas are multistoried ones. Early pagodas were usually wooden and had quadrangle, hexangle, ocatagonal and twelve sided ichnographies. During the Sui and Tang dynasties, pagodas tended to be stone and brick. In the Liao Dynasty, solid pagoda appeared. After, in the Song, Liao and Jin dynasties, flower pagodas were introduced which were decorated with assorted carved flowers, honeycombed shrines, animals and Buddha and disciple sculptures, looked like flowers. Generally speaking, pagodas became more and more decorative.
The main reasons early pagodas in China had many storeys were, first, since pagodas were originally built to preserve Buddhist relics, which were considered the most sacred objects in the world, representing Buddha, they should be majestic and striking in style. Second, multistoreyed buildings were traditionally used by the ruling class to show off its power and wealth; they were also believed to be the residences of the immortals; therefore they were most suitable for enshrining the mysterious Buddha, the highest saint among the immortals. Third, high buildings of many storeys were usually awe inspiring and mysterious looking.
Chinese pagodas belong to several categories. Based on their style of construction, they can roughly be classified into four categories
First, is the multi-story pagoda. It resembles a multi-story tower with protruding up-turned eaves. The oldest and tallest of this type is a magnificent Yingxian Wooden Pagoda. Built in 1056(in Liao Dynasty) extant oldest and highest wooden Buddhist Pagoda is located in Yingxian County in Shanxi Province. The Pagoda consumed at least 3,500 cubic meters of wood. The pagoda is octagonal in shape, presenting an outward appearance of a five-storey and six-eave building, but actually it is nine-storeyed. Not even a single nail was used and the whole structure is weathered over 900 years of wind and storm and remained intact despite many strong earthquakes. It is indeed a masterpiece of ancient Chinese architecture.



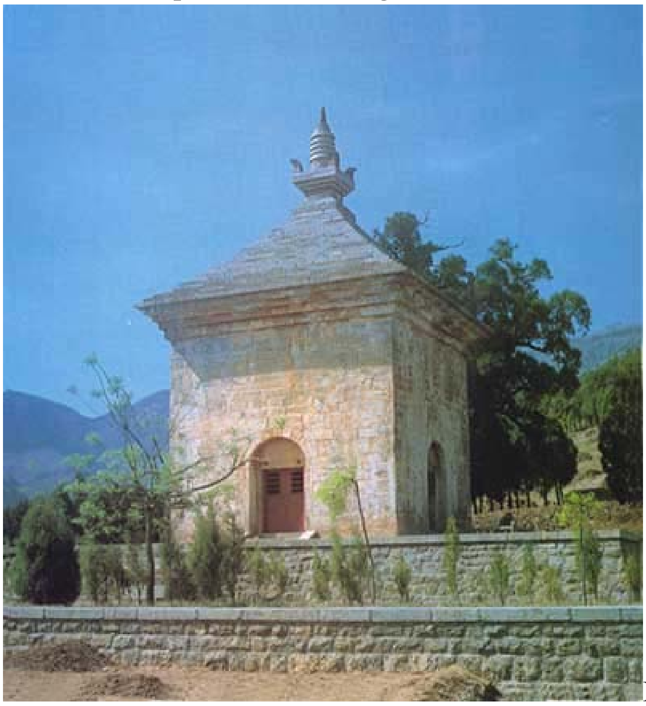
Figures 2: Yingxian Wooden Pagoda

Another type is the Miyanta. It takes its name from the many tiers of closely-set eaves at the top. Most pagodas of this sort are built of brick and stone. They are without doors or windows, except for holes that let in light. The earliest example is at the Songyue Temple on Mt.Songshan in Henan Province. Built in 520, it stands 40 meters high and has 12 sides capped by 15 tiers of eaves. (Figures 2)



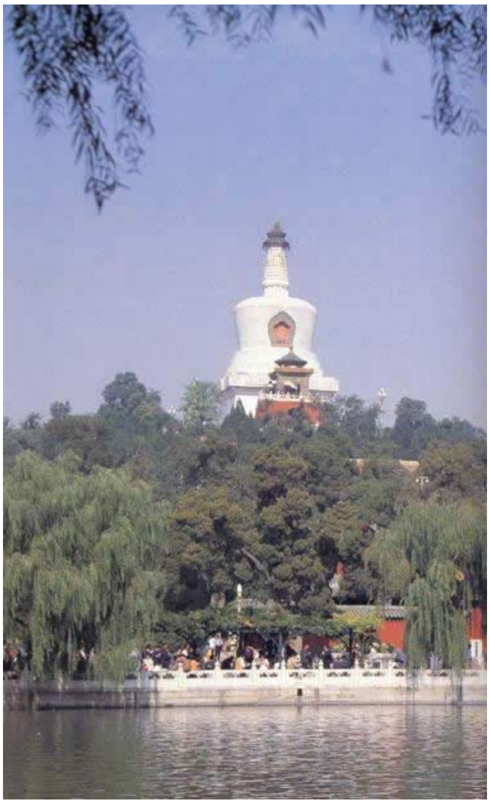
Figures 3: Songyue Temple Pagoda

The third style is the pavilion-style or one-story pagoda. Most of them were used as tombs for abbots and other high-ranking monks. The earliest of these still extant is the 1,400-year-old Simen Pagoda at the Shentong Temple in Shandong Province, East China. It is square, with a single roof and one door on each side.



Figures 4: Simen Pagoda

The fourth is the Lamaist style. Similar to Indian dagobas, the pagoda is a dome-shaped structure set on a large pyramidal platform. One famous example is the White Dagoba in Beijing's Beijing's Beihai Park.



Figures 5: White Dagoba

Ancient Chinese pagodas may stand alone or in groups. The largest group of pagodas is the Pagoda Forest at the famous Shaolin Temple in Henan Province. This group is composed of 220 brick and stone structures.

Figures 6: Pagoda Forest

Another well-known example is the unique Bamboo-shoot Pagoda in Yunnan Province. It consists of a central pagoda in the shape of a lotus flower, surrounded by eight smaller ones. From a distance the group suggests a bamboo thicket.

Figures 7: Bamboo-shoot Pagoda

Chinese pagodas may be square, polygonal or circular with each story separated by projecting roofs or eaves. A typical pagoda has four main elements: the underground hall, the platform, the body and the steeple.

The underground hall usually housed sacred relics, books and paintings. This underground palace was similar to the underground palaces of the mausoleums of emperors and kings in ancient China, but it was usually much smaller and contained fewer funerary objects. The most important thing in an underground palace of a pagoda is a stone container with layer upon layer of cases made of stone, gold, silver, jade and other materials. The innermost case contains the Buddhist relics. The funerary objects in the palace may include copies of Buddhist scriptures and statues of Buddha. Underground palaces were usually built of brick and stone in square, hexagonal, octagonal or round shapes. Occasionally such a structure was built inside the pagoda or semi-underground.

The platform may be a simple structure, or it may be elaborately decorated. It supports the whole superstructure. In early times most pagodas had relatively low bases. Some bases are only ten or twenty centimeters high. They soon become indistinct and even unrecognizable from the ground after being damaged over the years. During the Tang Dynasty, in order to make pagodas such as the Big and Small Wild Goose Pagodas in Xi'an look magnificent, huge bases were built under them. Large bases were also added to pavilion-style pagodas during the Tang Dynasty, for example, the Pagoda of Monk Fanzhou in Anyi of Shanxi Province and the Dragon and Tiger Pagoda at Shentong Temple in Licheng near Jinan.

The shaft or the main part of the pagoda may be either solid or hollow. Solid pagodas are filled with bricks, stones or rammed earth. Occasionally, a wooden framework is installed inside a solid pagoda to strengthen the bearing capacity of outreaching parts of the pagoda. A spiral stairway sometimes leads up through this central shaft. Images of the Buddha are usually carved on the outside walls. Pagodas' roofs are often crowned with ornate carvings or studded with jewels.

Every pagoda is surmounted by a steeple, sometimes pointed and sometimes ball-shaped. They vary greatly in style and building materials. The most commonly used building materials for steeples are bricks, stones and metals. The steeple, as the tallest part of the pagoda, is extremely important. In Chinese it is called Cha, meaning land or territory representing "the country of Buddha."

The generation of the body shape of multi-storey pagodas

Pagodas were the delight of Chinese landscape-architects, and were located in variety of different situations. They were often in early times built adjacent to a temple or monastery as works of religious enthusiasm. However, the Chinese were very fond of erecting multi-storey pagodas on hill tops or mountain slopes, and they were placed so that they were axial with the entrances to a temple or place, and could be seen through the main gateway at the end of the vista.

As the multi-storey pagoda is tall enough to change the skyline of a city and can become a scene of a city. Now we still often build or rebuild multi-storey pagoda as a scenic sport. The restoration of the Leifeng Pagoda, one of the most famous ancient architectural structures in China, will be completed this year in Hangzhou, the capital of Zhejiang Province, in eastern China. And in Changshu, a big city in Jiangshu Province, It will build a new pagoda in Tianning Temple. This pagoda will be 150 meters high totally. Fortunately I take part in the architecture design of this pagoda.

Figures 8: Leifeng Pagoda (before it felled at 1924)

Figures 9: Simulation of the pagoda in Tianning Temple

Every multi-storey pagoda has his unique shape of his body. This shape show the character type of the pagoda, such as thin like young girl and fat as mature lady. Now we focus on the generation of the shape of a pagoda.

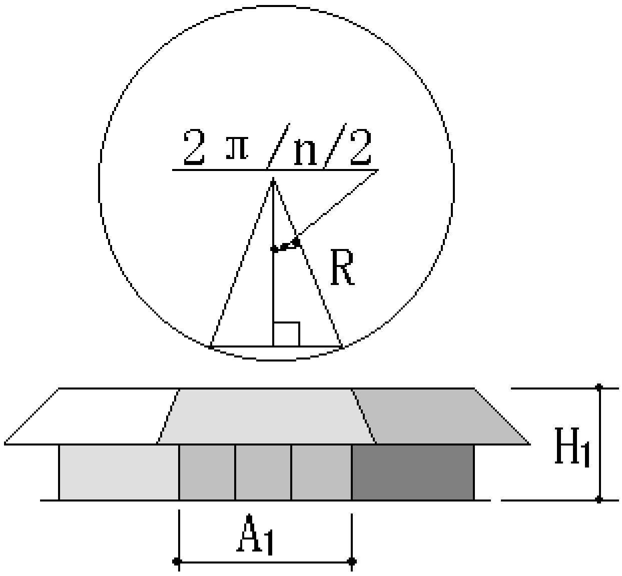
As mentioned earlier, multi-storey pagoda was just a serial of pavilion-like building added for effect and then more added until a tower-like shape was achieved. Each storey diminishing in which while simultaneously each order is reduced in height. So we just need decide the size of the pavilion on each level.

When we design a pagoda, the first precondition is the place where the pagoda will be located. It will decide the size of the end of the pagoda. As all the plane of pagodas is regular polygon, we can signify the size with the radius of the circumcircle, symbolic representation with **"R_1"**. After we decided the number of the sides **"n"**, we can get the length **"A_1"** of each side of the first floor of the pagoda.

$$\mathbf{A_1} = 2*\mathbf{R_1}*\mathrm{Sin}(2\pi/\mathbf{n}/2) = 2*\mathbf{R_1}*\mathrm{Sin}(\pi/\mathbf{n}) \qquad (1)$$

As each side is separated into three rooms (or bays, Jian in Chinese) by four columns, and each room is almost square on elevation. So the higher of the column of the first floor is third part of the length of the side. And the higher of the roof of this floor is equal the higher of the column. So the higher of the first floor **"H_1"** is:

$$\mathbf{H_1} = 1/3*\mathbf{A_1}*2 = 4*\mathbf{R_1}*\mathrm{Sin}(\pi/\mathbf{n})/3 \qquad (2)$$



Figures 10:The first floor of pagoda

Now we get the main size of the first floor: $\mathbf{R_1}$, $\mathbf{A_1}$ and $\mathbf{H_1}$. Then we decide the main size of the next floor: $\mathbf{R_2}$, $\mathbf{A_2}$ and $\mathbf{H_2}$. This time we begin at the higher of this floor. We can set a parameter **"K_1"** represent the reduce rate of the higher, so the higher of the second floor **"H_2"** is:

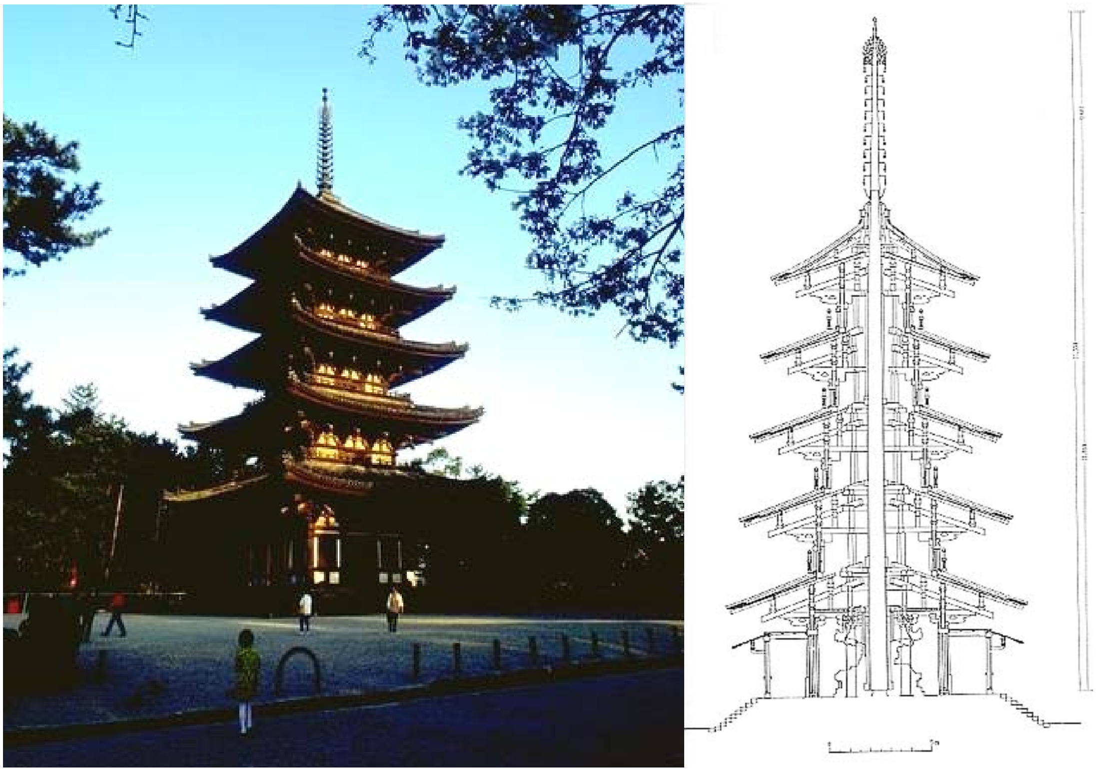
$$\mathbf{H_2} = \mathbf{H_1}*(100-\mathbf{K_1})\% = 4*\mathbf{R_1}*\mathrm{Sin}(\pi/\mathbf{n})/3*(100-\mathbf{K_1})\% \qquad (3)$$

Then, we can get other main size of the second floor:

$$\begin{aligned}\mathbf{A_2} &= 3*\mathbf{H_2}/2 = 1.5*\mathbf{H_2} = 1.5*(4*\mathbf{R_1}*\mathrm{Sin}(\pi/\mathbf{n})/3*(100-\mathbf{K_1})\%)\\ &= 2\mathbf{R_1}*\mathrm{Sin}(\pi/\mathbf{n})*(100-\mathbf{K_1})\% = \mathbf{A_1}*(100-\mathbf{K_1})\% \qquad (4)\end{aligned}$$

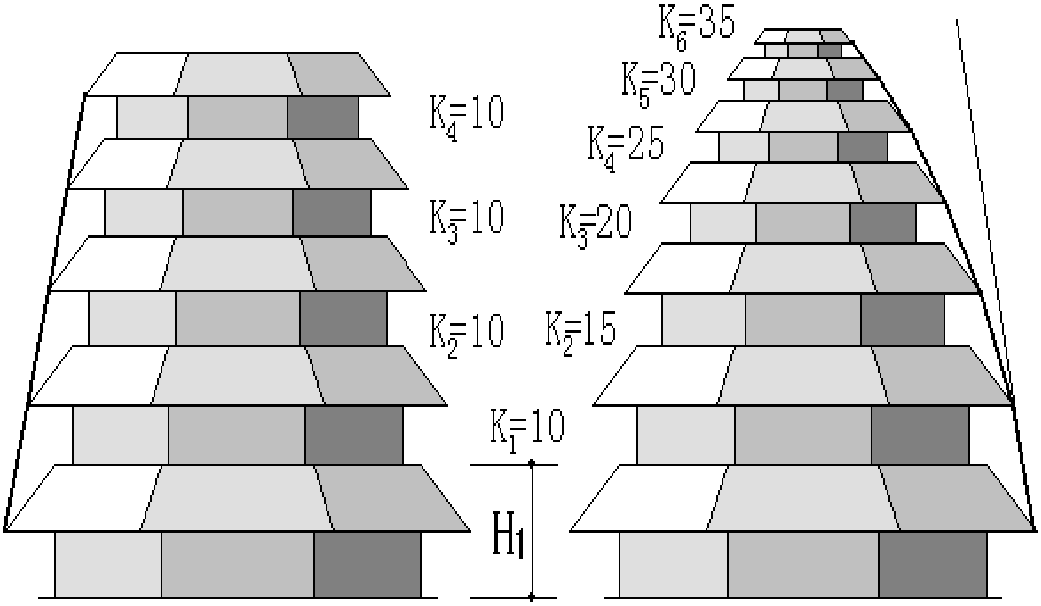
$$\begin{aligned}\mathbf{R_2} &= \mathbf{A_2}/(2*\mathrm{Sin}(\pi/\mathbf{n})) = 2\mathbf{R_1}*\mathrm{Sin}(\pi/\mathbf{n})*(100-\mathbf{K_1})\%/(2*\mathrm{Sin}(\pi/\mathbf{n}))\\ &= \mathbf{R_1}*(100-\mathbf{K_1})\% \qquad (5)\end{aligned}$$

Of course the reduce rates of the main size of the floor are equal, because they reduce both in plane and elevation.
Then we can set a parameter **"K_2"** represent the reduce rate of the **3rd** floor, and **"K_3"** for the **4th** floor, and **"K_4"** for the **5th** floor, etc.
In the Tang Dynasty (618-906A.D.), pagodas were usually simple, square structures, and each floor has equal reduce rate, its' mean "$K_1= K_2= K_3= K_4= K$…"Though the original pagoda before the Tang Dynasty cannot be traced, we can still learn the shape of a pagoda in a temple during the early period of Buddhist development in China from Japanese temples. In Japan the pagodas were introduced from China with Buddhism. They are usually square in plan and five stories high, each story having its projecting roof. Generally made of wood, they exhibit superb carpentry craftsmanship. The Horyuji pagoda near Nara, of the 7th cent., is a noted example.



Figures11: The Horyuji pagoda near Nara, Japan

After the Tang Dynasty, the shape of the pagoda was developed. The reduce rates of the main size of each floor are no longer equal. They are increased continually, its' mean "$K_1< K_2< K_3< K_4< K$…"such as "$K_1=10$, $K_2=15$, $K_3=20$, $K_4= 25$…"So the top of the pagoda shrink more quickly. The outline of the shape becomes a parabola.



Figures12: Two pagodas with different parameter

Usually, the number series of the reduce rates are changed in accordance with the mystery traditional Chinese theory of numbers, such as “0, 9, 13, 17, 21…” The odd number means Yang in Chinese (Yang, male, sunward, positive, etc.).

Figures13: Tianning pagoda in Hebei

The actuality and the future

There are more than 3000 extant ancient pagodas in China now. Most of them are multi-storey pagodas. Each pagoda has his unique number series of the reduce rates. If we build the database of these pagodas, we can analyze these data and find the law of them. We can get the function of them, then use these control function we can generate the shape of pagodas automatically.
This method of the generation of the pagodas is very simple and rough. Further, we can set more parameter to control the shape, such as the ratio between the length of the side **"A"** and the higher of the floor **"H"**, the ratio between the higher of the column and roof, the ratio between the higher of the steeple and body, the ratio between the higher of the column and the depth of the eave, etc. Then we will make the generation of pagodas more accurately and freely.
Now we have no more chance to build a new traditional Chinese pagoda, but the spirit of these pagodas express the spirit of ancient China, it's also become a traditional Chinese spirit. The successful usage of the spirit is the shape of the 88-storey Jinmao Tower, located in Pudong (east of Huangpu River), in Shanghai.

Figures13: The Jinmao Tower

The 420.5-meter-tall building is the tallest building in China, the second tallest in Asia, houses the tallest hotel ever built and is currently the third tallest building in the world! It is considered combing the traditional Chinese architecture and world's latest technology.
Architects designed the building around the theme of the Chinese pagoda and the number eight, which the Chinese consider lucky. The lowest segment of the building is sixteen stories high and each succeeding segment is 1/8th smaller than its predecessor.
Except pagodas, the traditional Chinese architecture also has its inner law. If we study more of them with generate method, we will find more useful law to help us create new architect with traditional Chinese spirit. we hope more scholar all over the world spend more attention on both generate design and Chinese culture.

pCM (pure C Music): a real-time music language

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Abstract

In order to put to work the facilities offered by the gesture interfaces realised at cART project of CNR, Pisa, I started writing basic libraries for processing sound and for driving the gesture interfaces. In the long run the framework became a very efficient, stable and powerful "music language" based on pure C programming, that is "pure-C-Music", or pCM. This programming environment gives the possibility to write a piece of music in terms of synthesis algorithms, score and management of data streaming from gesture interfaces. The pCM framework falls into the category of the "embedded music languages" and has been implemented using one of the most popular C compilers or better, multiplatform development systems: Metrowerks' Code Warrior. As a result a pCM composition consists of a CW project which includes all the necessary libraries, including a DSP.lib consisting of a number of functions able to implement in real-time the typical synthesis and processing elements such as oscillators, envelope shapers, filters, delays, reverbs, etc. The composition itself is a C program consisting, mainly, of the *Orchestra*() and *Score*() functions. Everything here is compiled into machine code and runs at CPU speed.

1. Introduction

The activity of cART (computerArt Project of C.N.R., Pisa) is characterised by the design and the realisation of systems and devices for gesture control of real-time computer generated music in order to give expression to interactive electro-acoustic performances[1], as it happens in traditional music. The "wireless technology" (or "touchless technology") paradigm has been taken into consideration [2]. Main targets of the research consist of the implementation of models and systems for detecting gestures of the human body that becomes the natural interface able to give feeling and expressiveness to computer based multimedia performances. The term "multi-modality" [3] is often related to these typologies of interfaces just for emphasising that combining different modes of perception, becomes relevant for the performer and for the audience that, at the end, is the final "user" of the performance.

At cART, attention has been focused in designing and developing new original general purpose man-machine interfaces taking into consideration the wireless technologies of infrared beams and of real-time analysis of video captured images [4]. Specific targets of the research consist of studying models for mapping gesture to sound; in fact, in electro-acoustic music nothing is pre-established as in traditional music and instruments where there exist precise and well consolidated timbric, syntactic (harmony) and fingering systems of reference. The basic idea consists of remote sensing gesture of the human body considered as a natural and powerful expressive "interface" able to get as many as possible information from the movements of naked hands. A brief description of systems and devices we developed, follows. Video clips of performances realised with our gesture interfaces can be found at the reported web page.

1.1 Twin Towers

This device consists of two sets of sensing elements that create two zones of the space, i.e. the vertical edges of two square-based parallelepiped, or virtual towers. At the time the first prototype was realised (1995), the shape of the beams suggest us the profile of the late Twin Towers in New York (we chose to keep the name in tribute to the victims of the tragedy). The measurements of distance of the different zones of the hands are performed by the amount of reflected light captured by the receivers (Rx's) and are quite accurate in respect to the irregularity, in shape and colour, of the hands palms. Voltage analog values coming from the Rx's are converted into digital format and sent the computer about 30 times/sec. The computer then processes data in order to reconstruct the original gesture [5,6]. It's so possible to detect positions and movement of the hands such as height and side and/or front rotations.

1.2 Imaginary piano

In the Imaginary Piano a pianist sits as usual on a piano chair and has in front nothing but a CCD camera few meters away pointed on his hands. There exists an imaginary line at the height where usually the keyboard lays: when a finger, or a hand, crosses that line downward, proper information regarding the "key number" and a specific messages issued in accordance of "where" and "how fast" the line has been crossed are reported. Messages are used for controlling algorithmic compositions rather than for playing scored music.

1.3 PAGe system

Another application based on the video captured image analysis system is PAGe, Painting by Aerial Gesture, which allows video graphics real-time performances. PAGe has been inspired and proposed by visual artist Marco Cardini (www.marcocardini.com) who suggested the idea of a system able to give the possibility of "..painting in the air.." and to introduce a new dimension to painting: time. PAGe has been designed by L.Tarabella and developed by Davide Filidei. PAGe allows Cardini, who also performs on stage, to paint images projected onto a large video screen by moving his hands in the air [7].

1.4 Mapping

The different kinds of gestures such as continuos or sharp movements, threshold trespassing, rotations and shifting, are used for generating sound event and/or for modifying sound/music parameters. For classic acoustic instruments the relationship between gesture and sound is the result of the physics and mechanical arrangement of the instrument itself. And there exist one and only one relationship. Using a computer based music equipment it's not so clear "what" and "where" is the instrument. From gesture interfaces, such as the infrared beam controller or image processing based systems, to loudspeakers which actually produce sound, there exist a quite long chain of elements working under control of the computer which performs many tasks simultaneously: management of data streaming from the gesture interfaces [8], generation and processing of sound, linkage between data and synthesis algorithms, distribution of sound on different audio channels, etc. This means that a music composition must be written in term of a programming language able to describe all the components including the modalities for associate gesture to sound, also said how to "map" gesture to sound. The “mapping” makes therefore part of the composition [9].

2. A new real-time music language

In order to put at work the mapping paradigm and the facilities offered by the gesture interfaces we realised, at first we took into consideration the most popular music languages: MAX/DSP and Csound. Unfortunately, both languages resulted not precisely suited for our purposes mainly because Csound was not so real-time as declared and Max was not so flexible for including video captured images analysis code. Using two computers (first one for managing interfaces, second one for audio synthesis) connected via MIDI, resulted awkward and inefficient. We started writing basic libraries for processing sound and for driving the gesture interfaces bearing in mind the goal of a programming framework where to write a piece of music in terms of synthesis algorithms, score and management of data streaming from gesture interfaces. On the long run the framework became a very efficient, stable and powerful “music language” based on pure C programming, that is “pure-C-Music”, or pCM. “pCM” falls in the category of the “embedded language” and needs a C compiler in order to be operative; at first this may appear an odd news, but consider the good news of getting a compiled code of a synthesis algorithm which generate and process sound running many times faster in respect to Csound which, on the other hand, is an interpreted language.

2.1 pCM, pure C Music

pCM has been implemented using one of the most popular C compiler or better, multiplatform development system: Metrowerks Code Warrior. As a result a pCM composition consists of a CW project which includes all the necessary libraries including, once again, a DSP.lib (Digital Signal Processing library) consisting of a number of functions (at the moment more than 50) able to implement in real-time the typical synthesis and processing elements such as oscillators, envelope shapers, filters, delays, reverbs, etc.. The composition itself is a C program consisting of four void functions: *Init*(), *Orchestra*(), *Score*() and *End*() properly invoked by the main program which controls the whole “machinery”.

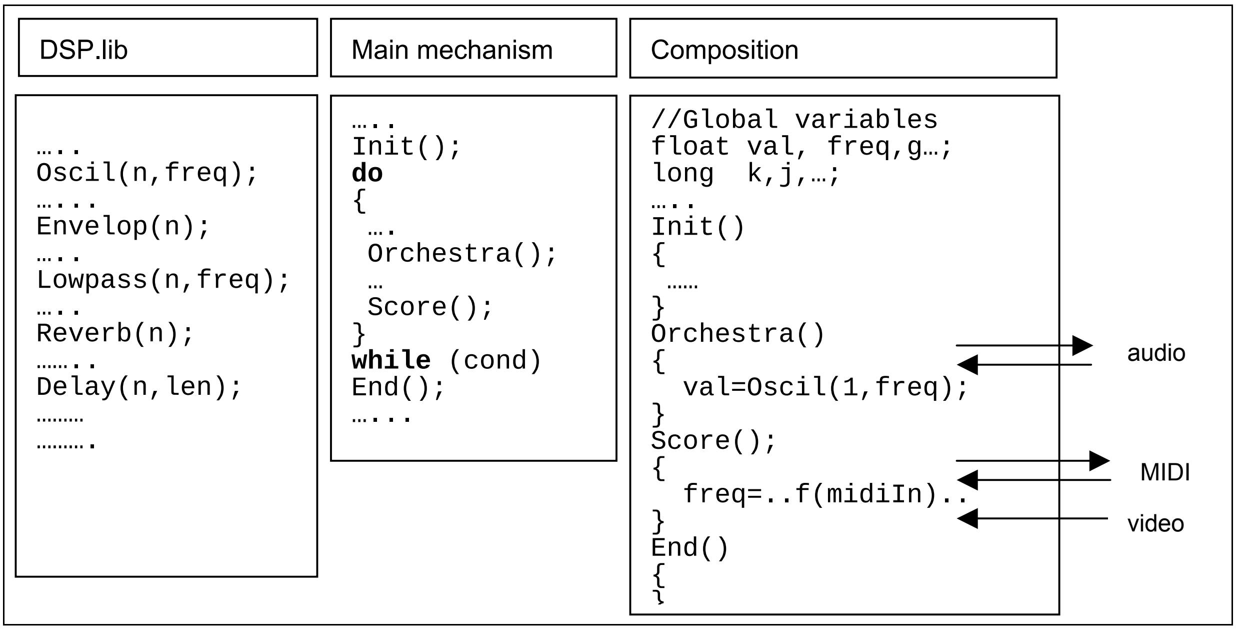

Fig.1 pCM principle of operations

For practical reasons of consistency it's a good idea the four functions make part of the same file which also includes declaration of the variables visible by the all functions and especially from *Orchestra*() and *Score*(). Everything here is written following the C syntax: synthesis algorithms, score and declaration of variables and data structures. Everything here is compiled into machine code and runs at CPU speed. The *Init()* function includes everything regarding initialisation and/or loading such as envelopes, tables, samples, delays, reverbs, variables and data structures. Usually it also includes calls for opening Midi, TCP/IP, Audio and/or Video Input channels. As a counter part the *End*() function is called at the end and is used for closing channel and disposing previously allocated memory.

2.2 Orchestra and instruments

An instrument is defined in the *Orchestra()* function and consists of code for sound synthesis and processing; it is continuously called at audio sampling rate, that is 44100 times per second. An instrument is defined in terms of an ordinary C program (with all the programming facilities such as *for*, *do-while*, and *if-then-else* control structures) which calls functions belonging to the DSP.lib; assigning the results of the whole computation to two predefined "system variables" *outL* and *outR,* sound is generated. Look at the following simple example.

```
….
  sig  = ampli*Env(1)*Oscil(1,freq);
  outL = sig*pan;
  outR = sig*(1.-pan);
```

where *sig* is a local variable, *ampli*, *freq* and *pan* are global variables loaded by *Score*(), Env(1) and OscSin(1,freq) belong to the DSP.lib and sounds like that:

```
float Oscil (int nOsc, float freq)
{
      float pos;
      pos = oscPhase[iN][nOsc] + freq;
      if (pos>=tabLenfloat) pos=pos-tabLenfloat;
      if (pos<0) pos=pos+tabLenfloat;
      oscPhase[iN][nOsc] = pos;
      return Tabsen[(long)pos];
}

float Env (int nEnv)  // One-shot envelope
{
  float  vval,vv,pos;
  long   ntabEnv =envNum[iN][nEnv];
  pos  = envPos[iN][nEnv];
  vval = *(envTable[ntabEnv] + (long)pos);
  if((long)pos<envLenght[ntabEnv]) envPos[iN][nEnv]=pos++;
  return vval;
}
```

2.3 The score

Once again the *Score*() is a C function which prepares parametric values and loads the global variables (*ampli*, *freq* and *pan* in the example) used by the active instrument in Orchestra(). There exist different modalities for writing a score: following the algorithmic composition approach, writing sequences of predefined events, getting values coming from the external gesture interfaces and, finally, combining in different ways these techniques.

Suppose we want to control in real-time a very simple instrument using movements of the mouse by linking the vertical position to frequency and the horizontal position to left-right panning. In the MacOs environment, the mouse position is returned invoking the GetNextEvent(..) tool-box function which leaves the x,y position values in the "Event.where.v/h" variable and used as follows:

```
horiz  = Event.where.h/1023.;
freq   = Event.where.v+200.0;
```

These two lines make part of the *Score*() which is automatically and repeatedly called by the main mechanism. Since the mouse spans between 0 and 1023 horizontally and from 0 to 767 vertically, the variable *pan* and *freq* communicate proper values to the instrument for changing frequency and panoramic position. The following example explains the dynamic relationship between the Orchestra and the *Score*.

3. An example of composition

This listing reports a real working example.

```
//======================== FMouse =======
//  global  variables

float    freq,pan,vert,val;
int      enva, samp;
bool     mousePressed;
Point    position;
//-----------------------------------------------------------
int Init ()
{
  float env[]={3, 0.0,0.0, 0.1,1.0, 4.0,0.0};
  enva  = NewLinEnv(env);
  mousePressed=false;
  OpenAudio();
}//---------------------------------------------------------
void Finish()
{
  DisposeEnv(enva);
  CloseAudio();
}//---------------------------------------------------------
void  Orchestra() // simple FM
{
  iN = 1;
  if (noteon[1]) TrigEnv(1);
  val  = Env(1)*Oscil(1,freq+Oscil(2,freq*1.5));
  outR = val*pan;
  outL = val*(1.-pan);
}
//----------------------------------------------------------
void Score ()
{
  if (Button() && !mousePressed)
  {
     iN=1;
     noteon[iN]  = true;
     position    = theEvent.where;
     pan         = position.h/1023.;
     freq        = position.v+200.0;
     mousePressed= true;
```

```
  }
  if (theEvent.what==mouseUp) mousePressed=false;
}//------------------------------------------------------------
```

A composition consists of five different sections: -1: global variables declaration for communication between *Orchestra* and *Score*; -2: *Init*(), for opening channels, declaring envelopes and delay lines, loading samples, etc..; -3: *Orchestra*() where sound synthesis and processing algorithms are defined; -4: *Score*() defined in terms of algorithms and management of input data stream coming from external gesture controllers –5: *End*() for closing channels and disposing envelopes and samples. Functions in bold belong to the DSP.lib. *Orchestra* is automatically called at 44.100 Hz sampling rate and has the priority on the CPU request; Score is called 50÷100 times per second depending on the complexity of the synthesis and processing algorithm defined in *Orchestra*.

Each time the mouse button is depressed (*Score* has the control) the predefined boolean variable *noteon[iN]* is set to true; then, the *Orchestra* trigs the envelope defined in Init and sound is produced with pitch related to the mouse vertical position and pan position related to the mouse horizontal position. The "system" predefined *iN* variable allows to select different instruments inside the same *Orchestra*: what follows the *iN* variable assignment is related to that instrument. Actually, the layout of both *Score* and *Orchestra* is more complex and consists of a number of " *case N: break;* " blocks which define different situations at micro level of sound processing and at macro level of events control.

3.1 The DSP.lib (Digital Signal Processing library)

This is the library of predefined functions which perform the micro level computation for generating and processing sound. What follows is a very small excerpt of the current collection of functions at the moment developed and upgraded when requested.

float Noise();	*This set of functions performs signal*
float Oscil (int nOsc, float freq);	*generation in accordance to the name*
void TrigKarplusStrong(int nOsc);	*and parameters reported.*
float KarplusStrong (int nOsc, float freq);	
int NewLinEnv (float v[]);	*Usually called in the Init*
void TrigEnv (int nEnv);	*This starts the scanning of the envelope*
float Env (int nEnv);	*Used in Orchestra.*
int LoadSample (char nomesmp[]);	*This function load a sample with the specified*
void TrigSample (int nSmp);	*name (for example: sn=LoadSample("whistle"));*
float Sample(int nSmp);	*This scans and reporst the current sample*
float Bandpass(int nFilt, float inp, float freq, float q);	*This is the set of usual filters.*
float Reson(int nFilt, float signal, float freq, float band);	*Used in Orchestra*
float Lowpass(int nFilt, float signal, float cutfreq);	
float Hipass(int nFilt, float signal, float cutfreq);	
void NewDelay(int nDly, float dur);	*Define a new delay line of specified duration.*
void PutDelay(int nDly, float val);	
float GetDelay(int nDly);	
void NewReverb(int nRev);	*Such as NewDelay, called in Init or Score.*
float Reverb(int nRev, float sign);	*Used in Orchestra*

```
void  SetFader( int nFad, float startval, float endval, float time);
void  TrigFader(int nFad);
float  Fade(int nFad);
```

A Fader is an asynchronous task which starts when TrigFader is called and repeatedly used in Orchestra and in Score.

```
void  OpenAudio();
```

Opens and starts the available audio channel

3.2 Other facilities

It's also possible to generate (offline or in real-time under control of data streaming from gesture interfaces) sequences of events automatically activated by the Scheduler(), a special mechanism which triggers sounds at the right times and change parametric values in the instruments of an *Orchestra*. Other facilities supported by the pCM framework are:

void	CDtrackSearch (short nTrack);	*activation of sound tracks of CD*
void	CDplay ();	*with complete control of track selection*
void	CDpause();	*pause command,*
void	CDstop ();	*stop command*
void	CDvolume (short vol);	*and volume control.*
Void	Record("soundFilename.aiff",60)	*This is called in the Init and starts the recording of the global sound result onto memory with no loss of quality. The file is saved onto disk in .aiff or .wav format.*

```
UDPSend((void *) &udp_out, sizeof(long));
UDPReceive((void *) &udp_in, &theUDPDataSize);
```

Communication via TCP/IP

```
void    OpenMidi();
void    GetMidiData();
void    SendMidiMessage(int status, int data1, int data2);
void    NoteOn(int chan, int num, int vel);
etc..
```

Communication via MIDI

Finally, OpenVideo() allows to open a video channel and to grab frames coming from a video camera. A "videoCallBack" function is installed when the video channel is open and called as service interrupt routine when a new frame is digitalized and put into memory: analysis of images is performed by processing the planar x-y matrix of values corresponding to the pixels of frames. Extracted parameters values from the shape and positions of the performer hands are then used in real-time the Score part of a pCM project.

4. Conclusion and acknowledgements

The pCM framework has been efficiently used for composing and performing [10,11,12] many pieces of music under the control of the gesture tracking systems and devices realised at cART project in Pisa. It has been developed for Mac/Os environment and also included as special topic in the course of Computer Music I yearly teach at the Computer Science Faculty of Pisa University. Due to the great interest of the students towards pCM who really like programming and "put their hands" inside computers, a group of them, particularly skilled and hardworking, decided to port the pCM framework onto PC/Windows environment rewriting it following the Object Oriented paradigms and with the *obvious* name, they claim, pC++M. Thanks in advance to all of them.

Special thanks are due to Massimo Magrini who greatly contributed to set up the pCM main mechanism currently in use and the many facilities for data communication and audio processing. Also thanks to Roberto Neri who recently graduated in Electronic Engineering at Pisa University with a thesis regarding the upgrading of the pCM DSP.lib.

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Spatial Forms Generated by Music – The Case Study

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Abstract

This paper resulted from the first stage of an ongoing collaborative research between a multi-senses artist (R. T.) from New Zealand and an architect interested in generic architecture (M. D.) from Yugoslavia. The research examines potential relations between music and architecture and explores the ways music could be a source for generation of spatial forms, and vice versa, whether architecture might generate music. In the first stage of the research two different existing generic principles were combined. The graphical interpretation of the music served as a pattern for creating the spatial forms. In this experiment the Brahms's Hungarian Dance No1 has been used as an initial generator. The music is transformed into the sequence of linear drawings. Every single drawing potentially defines a spatial composition, while each single line represents an axis of the future spatial form. Together with geometric definitions there are some ambient values, like color, transparency and many others, that can be determined by music. After an overview of results, paper concludes with perspectives for future research that will include time as an additional dimension towards generating dynamic spatial concepts based on music.

1. Introduction

There are many interpretations of interdependences between music and space, especially of the space materialized in architectural form. Contemporary musicians receive commissions to write pieces of music for important events or even for particular buildings. One of the most recent examples is the Philip Glasses *Dancissimo* created for the new addition of the

Milwaukee Art Museum. In an interview for Architectural Record Philip Glass discusses the process of writing music for architecture:

“There’s a feeling - the idea is something to do with the idea of the structure of architecture and the structure of music. In architecture the structure is overt. The structure and function: isn’t that the whole idea of modern architecture, that structure and function are very connected? That, of course, is the secret of music: that structure and function - what we call content and structure, which I guess is very similar - the emotional content and the structure of music are very close. So there’s always been that kind of funny bond between architecture and music to begin with.”[2.].

Figure 1 Santiago Calatrava – Milwaukee Art Museum, Wisconsin, USA, the building that provoked composer Philip Glass to create a piece of music.

In another interview, related to his famous building “Tower of Winds” Japanese architect Toyo Ito discusses a possibility to translate architecture into music:

”I have been wanting to create an architectural space that is like a space in musical sound. The system in configuring sounds in music is determined by the composer. But how the player takes them each time makes a lot of difference in the spatial sound of the music created. Moreover, sounds die away, as time goes by. I would like to create such an architectural space. So I think virtual architecture existing in my consciousness can be well translated into something like music. But in reality, once a building is constructed on earth it can no longer be translated into music. I myself feel betrayed, as soon as I see a completion of my work.

But after all, music as well as architecture is a visualization of the time and construction of space. I hate to see the space in architecture freeze and continue to exist for a long time" [1].

Figure 2 Toyo Ito - "Tower of Winds", Tokyo

2. Combining the Two Generic Principles

In this project the two researchers from different fields (multi-senses art and architecture) combined their generic methods with aim to create a system of the spatial forms based on the music. The point of superimposition of these two processes was the particular stage where the graphical component explaining the music, become a guideline for generating the future spatial forms (Figure 3).

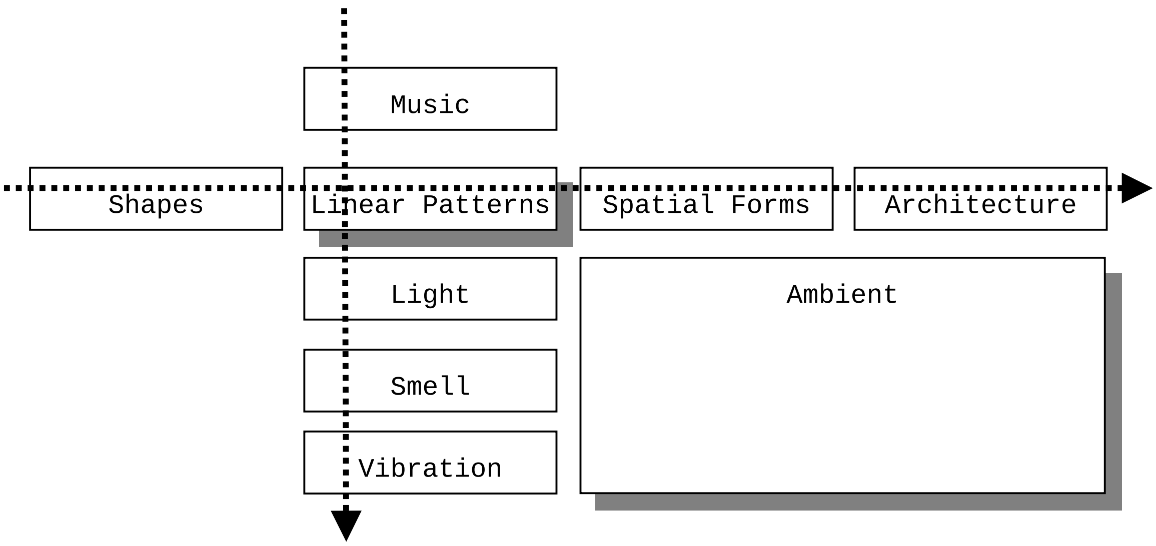

Figure 3 A Superimposition of the Two Generic Principles

The piece of music chosen for this project is Hungarian Dance No 1 by Johannes Brahms, well known and easily recognizable of its rhythm and dynamics.

2.1. Transforming Music Into The Light

Our nature and the things that we create, mirror the nature because we are inside nature. Gyorgy Doczi writes: “The basic pattern – forming process of proportional harmonies in nature shapes human creations; simple proportional relationships that create patterns in Nature and the arts”.

In this translation of Brahms Hungarian Dance No1 into coloured light the artist is experimenting with the imaginative vision of association triggered by sensory factors and the creation of a simulated synesthesia.

Brahms Hungarian dance No1 was recently included the multisensory Four Senses Performances with a symphony orchestra[1]. The artist used the stage lighting states that she had composed for this piece in performance as the basis of the color animation video that she created for this research.

The Brahms Hungarian Dance No 1 was translated into light by making an intuitive drawing (Figure 4) as a visual representation of the sound. This involved her perception of the phrases of the sound, which were coded into light, the pauses into dark, thus applying the method of correspondences between sound/silence, and light/dark.

[1] The concerts for the deaf, “Four Senses Concerts”, series of performances explores the interrelationship of inner and outer reality and the imaginative vision of association triggered by sensory factors. “Four Senses Concerts” (1999, 2002) series of performances in Auckland, New Zealand, with the Aotea Youth Symphony Orchestra also included mixed ability dance group Touch Compass, a deaf singing choir Hhands and sight-impaired vocalist Caitlin Smith.

Figure 4 Sequence generated of the first fifteen seconds of the Hungarian Dance No1.

The sequential colour states were composed using the sound drawings intuitively suggested to the artist by the phrases of sound. The pre-programmed light states for the theatre performance of the Brahms Hungarian Dance No 1 were created with a lighting plan and a PC based stage lighting program to make multiple sequences and cues used in improvisation.

The canvas of the whole orchestra was composed using saturated colours to achieve high degrees of retinal stimulation, brightness and afterimage.

According with the method which Raewyn Turner developed while working on a project with the New Zealand Symphony Orchestra during 1998 and in an earlier experiment with the Melbourne Symphony Orchestra, Australia, the orchestra is divided into sound groups each of which is assigned a colour and its complimentary (Tab.1).

Tab.1 The colours assigned to the groups of instruments of the symphony orchestra

Instrument	Principal colour	Complimentary
1st violin	Magenta	Deep blue-green
2nd violin	Violet	Deep amber
Viola	Medium blue	Orange
Basses, cellos	Deep blue-green	Magenta
Drums, percussion	Light red	Pea green
Sax, trombone, tuba	Lemon	Lavender
Trumpets	Deep amber	Violet
Clarinets, flutes, bassoon, oboes	Pea green	Light red
Horns	Orange	Medium blue
Piano	Bright rose	Sea blue

There were tactile cushions and balloons available in the auditorium (1000 seat of the Dorothy Winstone Theatre) for those with hearing disability.

The translations form a methodology in which one medium has been related to another. The correspondences established between sound/silence and colour/light/dark are creating systems and structures as a way of negotiating reflective and subjective connections between sensory experiences.

2.2. Generating Virtual Forms Based on Spatial Guidelines

The second generic principle is focused on creation of spatial (architectural) forms based on two primary variables - a shape that defines the cross-section of the future generated element and the guideline that serves as an axis along which we generate the spatial form.

While for the first element we chose simple shapes like square, rectangle or set of rectangles, the second element is more demanding and requires a definition of generic source for its creation. This generic source can be found on particular site (contour lines), can be predefined by urban planning requirements or urban context (roads, walkways, views…), by built environment, etc. In this case we used the music translated into drawings as a generic source for the spatial guidelines.

On this stage of the generating process the main issues were:

- Determination of the scale for the generated form, i.e. the ratio between the size of an initial shape and the line of generation.
- Finding the way to represent the duration of the particular sequence, within a static spatial form.
- Initial materialization of the form.

3. The Process

While applying the chosen shape that will define the constant cross-section of the generated form there are the two main properties, the scale that determine the future character, and the density, that represents the initiation of the future materiality of the spatial form.

3.1. Exploring the Scale and the Density of the Generated Form

The size of the shape that is used in the process of basic form generation, compared with the length of the spatial line defining the axis of the future form, determine the scale of the future form, which can be “geographic”, “urban”, “architectural” or “sculptural”. The most important in this case was the architectural scale where generated form got an architectural character.

The property of the generated form that we call the density is appropriate to the linear, “wire frame” representation of the generated form and can be treated as opacity, or transparency. In fact, it defines how expressive is going the future form to be, and it will depend on the intensity of the sound.

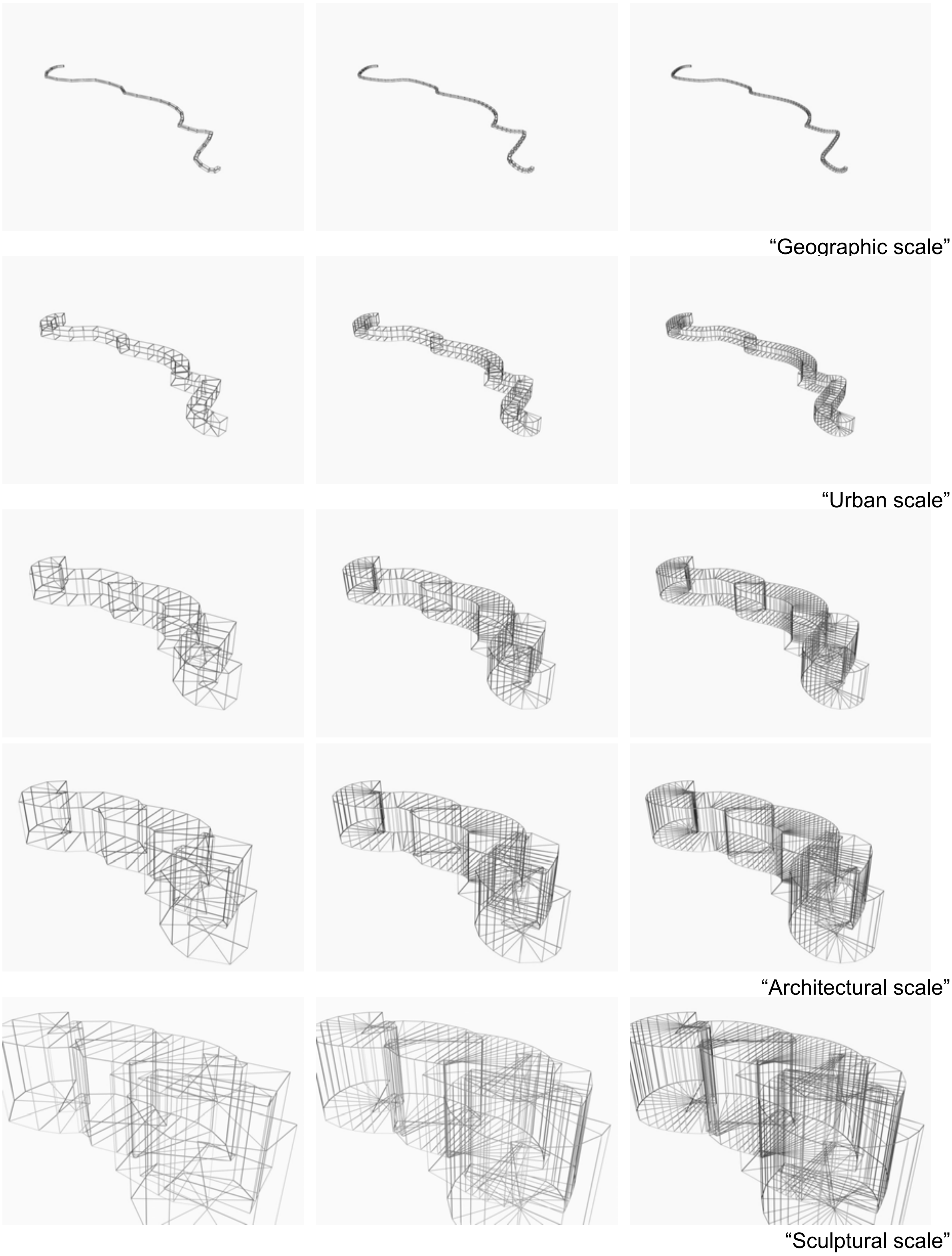

Figure 5 Examination of the scale and the density of the generated form.

3.2. Genesis

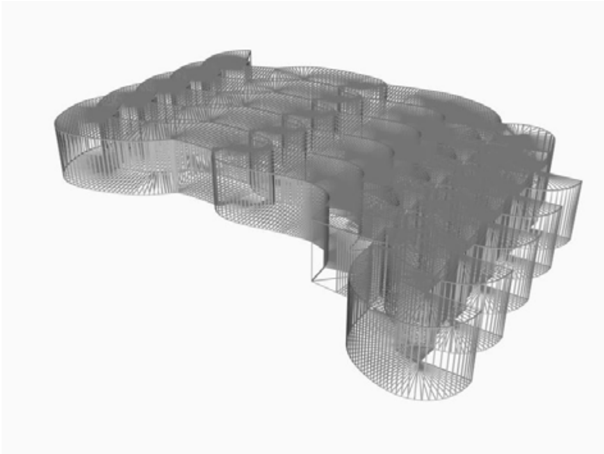

Figure 6 Genesis - Step 1; Duration of the sequence represented by multiplication of the form

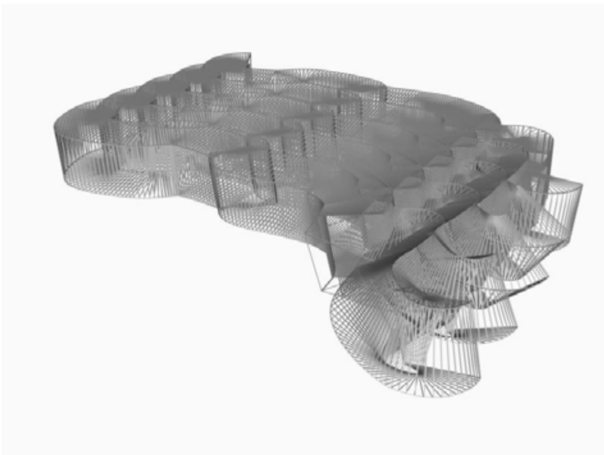

Figure 7 Genesis – Step 2; The part of the music accent transformed into the dynamics of the spatial form.

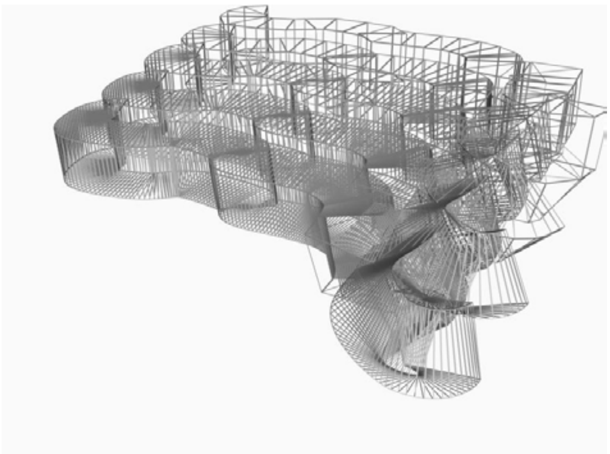

Figure 8 Genesis – Step 3; The intensity of the sound determining transparency of the generated form.

The set of images on the previous page (Figure 6 - Figure 8) illustrate the genesis of the spatial form based on the graphic representation of the first five seconds of the Hungarian Dance No1 (Figure 4), and the square shape applied in the "architectural scale". In the Step one (Figure 6) the duration of the music phrase is represented by multiplication of the basic generated form. The step two (Figure 7) shows the influence of the music accent at the end of the music phrase, represented by dynamics of the multiplied form. Finally, in the Step three the intensity of the sound determined the transparency of the particular parts of the form.

4. Spatial Expressions

The most exciting part of this process is the possibility to explore the generated spaces. Represented just by their linear frames, they allow full imagination of materialization and possible functionalities of the generated spaces. Next series of illustrations aim to show the spatial examination of the generated virtual space.

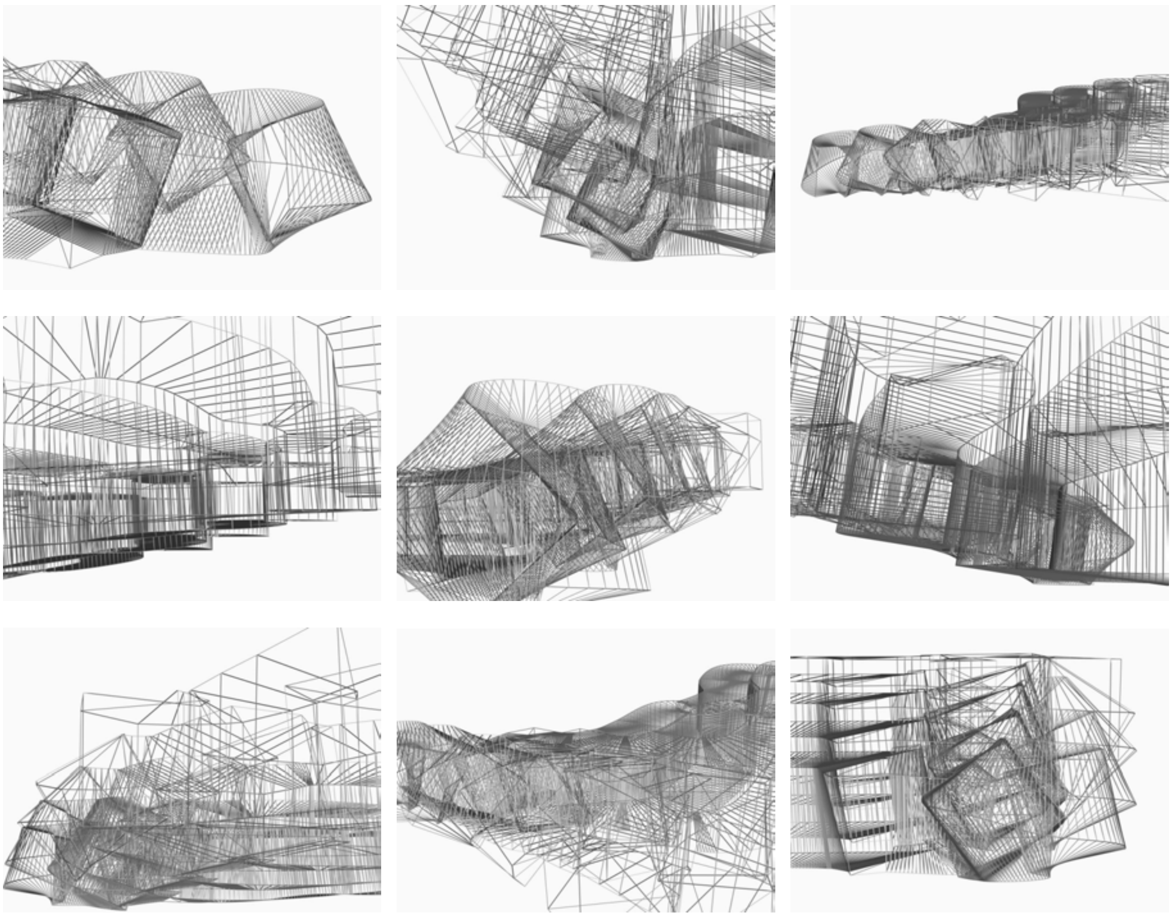

Figure 9 The Spatial expressions of the generated form.

5. Conclusion

The first stage of this research confirms that there do exist huge potentials related to experimentation in form generation based on music. It is completed entirely based on intuitive concepts, almost manually, without any parametric definition. The results are still in domain of "frozen", static form, represented by their linear appearance.

In our future researches we expect to introduce some ambient values like materialization, colour and light intensity, smell, etc. In this stage our intention is to examine introduction of dynamics effects related to the particular music into the creation of spatial compositions.

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A generative design system based on evolutionary and mathematical functions†

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Abstract

Previous work by Professor John Frazer on Evolutionary Architecture provides a basis for the development of a system evolving architectural envelopes in a generic and abstract manner. Recent research by the authors has focused on the implementation of a virtual environment for the automatic generation and exploration of complex forms and architectural envelopes based on solid modelling techniques and the integration of evolutionary algorithms, enhanced computational and mathematical models. Abstract data types are introduced for genotypes in a genetic algorithm order to develop complex models using generative and evolutionary computing techniques. Multi-objective optimisation techniques are employed for defining the fitness function in the evaluation process.

1. Introduction

A related paper [11] at this conference reviewed and described the theoretical foundations of the research led by Professor John Frazer in the past in the UK and in particular more recently in Hong Kong, on generative and evolutionary architecture design. In this paper, we focus on the technological implications and implementation techniques of a system for the design and visualisation of both abstractive 3D forms and domain specific architectural envelopes based

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on an integration of three main computational techniques. In this paper we discuss these techniques and present (1) computational tools for creating and exploring alternative complex forms, (2) stimulating the process of generating abstract but novel design concepts using generative design techniques, (3) linear and non-linear algorithms for modifying abstract forms to obtain complex forms through spatial or conceptual transformations. The facilities for providing these functions are integrated in a new system based on enhanced 3D solid modelling techniques with complex mathematical functions. The system kernel is compatible with object-oriented technology and 3D solid modelling and surface modelling standards. The system is demonstrated in an evolutionary architecture paradigm with a focus on how to generate visionary and creative forms. The complex forms generated and visualised using the developed system are promising. Our system has been implemented based on an integration of ACIS™ 3D solid modelling kernel and MatLab™ with a C++ graphical user interface. The integration of generative and evolutionary computation techniques with 3D solid modelling techniques provided a solid foundation for us to develop more domain specific applications. The system is fully compatible with commercial CAAD tools and systems, as well as rapid prototype facilities. Theoretical concepts of sophisticated surfaces and envelopes based on a library of basic building blocks of complex form have been built using evolutionary techniques and partial ordering theory of non-linear analysis.

A new type of genetic algorithm is also studied for our generative design system. We extended the classical powerful techniques from modern non-linear analysis theory to selection and optimisation of GA. These techniques included topological spaces and partial ordering. A Zorn Lemma type of iterative procedure is introduced. This attempt partially overcame the difficulty in implementing effective automatic selection in the application of genetic algorithms.

2. Mathematical models and 3D shapes

Nowadays, one of the most significant ways to understand a mathematical model is through computer visualization. However, due to the fully non-linear nature of many functions, it is not an easy task to develop accurate shapes for general non-linear functions. One way to solve this problem is the use of finite element analysis methods. There are several approximate techniques for non-linear functions, the simplest of which is a planar piece. More accurate techniques included NURBs approximation, polynomials approximation and others. It should be noted that it is always difficult to find a good balance between a better approximation and the acceptable computing time.

With the help of a solid modelling kernel with libraries of many sound geometric transformation and reasoning methods, we developed 3D solid model visualisations for complex functions in this project. A prototype system has been implemented based on an integration of ACIS 3D solid modelling kernel and MatLab with a C++ graphical user interface. Our basic geometrical objects for approximation are NURBs surfaced units. Our system is fully compatible with any commercial CAAD tools and systems, as well as rapid prototype facilities. A large number of object-oriented components of sophisticated surfaces and envelopes have been built. In particular, complex forms are classified as linear, quadratic, trigonometric function, exponential functions, root functions compounded functions, rotations, sphere and cylinder co-ordinates, implicit function. Computational mechanisms have also been developed with which these basic data structures and components can be visualised, combined or split to allow new data structures or new forms to be derived using generative techniques.

3. Simulating architectural envelopes

In this paper, our main concern is to generate architectural envelopes with their outlines determined by mathematical functions and evolutions. We use a multi-coding schema to represent the phenotypes. That is, we use continuous schemas with continuous functions, and discrete schemas with discrete functions.

It is well known that one of the most important and difficult problems in evolutionary design applications is the appropriate definition of the fitness function. It is this function that determines the selection and optimisation of the evolution and the final solution. In the literature, many authors used artificial selection techniques, which indeed helped to solve part of this problem. However, in a design application, exploration with artificial selection and optimisation with natural selection need to be combined in order to support the process of design from under-constrained design space of abstract concepts to a highly constrained space with well-defined variables and evaluation criteria. A wide range of design problems can be supported using generative and evolutionary techniques

To solve this problem, we adopted a multi-objective fitness function for optimisation, and a partial ordering technique derived from non-linear analysis to represent the complicated relationships among the candidate solutions from in populations generated during the process of evolution.

Figure 3.1 is a diagram of the functional components of the system we have implemented.

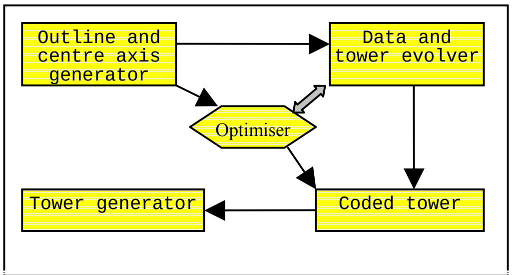

Fig 3.1 System functional components

4. Object Library and object class definition

We used an object-oriented representation in the system implementation. There are 47 object classes in the system object library including user interface classes. Among them, 17 classes are modelling classes. The base modelling class is CModel. Two derived classes are CAModel and CTower. There are three classes derived from CTower and 10 classes from CAModel. One of the CAModel derivations is CGABase, from which some evolution classes such as CGAModel and CANNModel are derived.

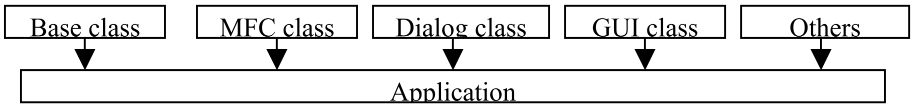

Fig 4.1 Class hierarchy

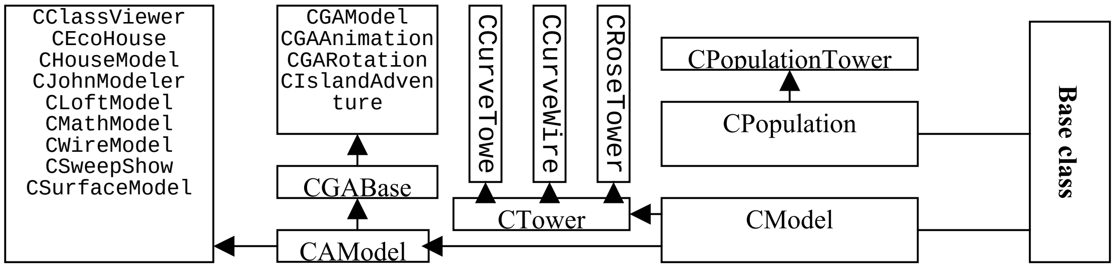

Fig 4.2 Class structures

The base class CModel provides interaction with the Acis 3D kernel and the basic file access. This class has two derivations, CAModel and CTower. The CTower class is the rendering encapsulation of the Acis APIs for the construction of 3D solid model classes. Another derivation is CAModel. In this class, useful encapsulations of rendering functions, for example, texture, colour, cutting etc, are integrated. Common operations such as SAT file save and refresh are also implemented in this class. Some geometrical construction functions are also encapsulated in this layer.

The main working classes in this project are at the next layer. The two derivation lines are CTower and CAModel. Along the first derivation line, there are three classes. The first class is CCurveTower. Below are the main operations for this class:

Table 4.1 Operations of class CCurveTower

```
double outline(double, double, double);
double outlineAxis(double, double, double);
void Create(double, double, double, int, int);
void Create(double, double, double, int, int, double*, double*);
void BuildCone(double, double, double, double, double, double);
void BuildConeTwo(double, double, double, double, double, double);
void BuildHat(double, double, double, double);
void BuildBase(double, double, double, double);
```

The construction of tower models is implemented in this class. The model is controlled by two functions. One is for the outline of the tower and the other is the centre curve. Figure 4.2 illustrates two example towers constructed using this class definition.

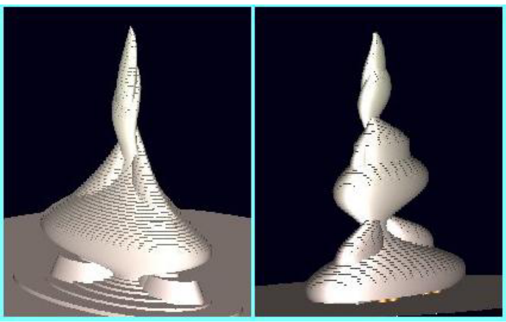

Fig 4.2 Towers created by class CcurveTower

The second class is CCurveWire. This is a class for constructing the wire-frame around the tower. Apart from the operations similar to the previous class, a new function called the bone-construction is provided as follows.

Table 4.2 Operations of class CCurveWire

void BuildBone(double*, double*, int, int);
void BuildBone(double, double, double, double, double, double, int, int);
void BuildBaseWire(double, double, double double);

The examples of models created using this class.

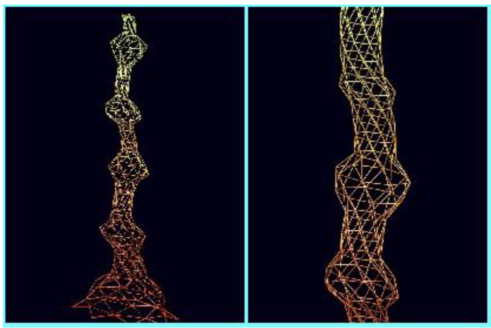

Fig 4.3 Wire frame created by the class CCurveWire

Another class is CRoseTower. The main functionality of this class is to create towers with more than two columns. A typical example is as follows.

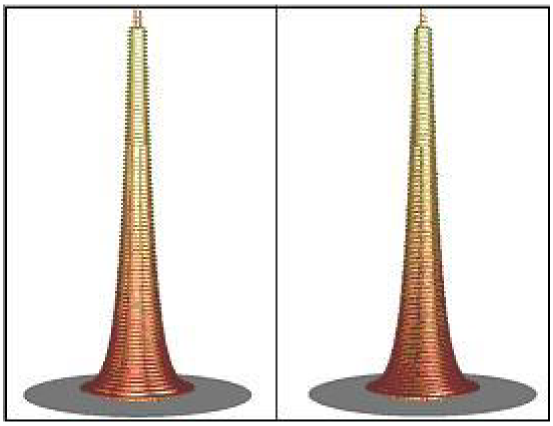

Fig 4.4 Five column tower and three column tower

A subclass at the second layer is CAModel. There are more class derivations than the class CTower. In fact, this class is the most important one in our system. And there are 10 derived classes from CAModel. Most of the classes perform a specific kind of architectural or mathematical model construction task.

Among these ten classes, CJModeler is one that focuses on mathematical modelling. Our main approach to complex form modelling is to combine discrete functions with NURBs surfaces. Some of the operations in this class are shown in the following table.

Table 4.3 Some operations of class CJModeler

```
void BuildP129SliceWire(double, double, double,   double, double, int, EDGE*&);
void BuildSweepPiece(double, double, BODY*&, BODY*&);
void BuildP132WingPiece(double, double, double, double, double, double, double, int, double*);
void BuildP127Piece(double, double, double, double, double, double, double* clColor);
void BuildP121TopPiece(double, double, double, double, double, double, double, double*);
void BuildLoftPiece(int, EDGE**, BODY*& my_body);
double nonSurface(double, double, double, double, int);
void BuildP123Wire(double, double, double, double, double,  double*, int nFlag);
void BuildPipeFromWire(position&, position&, EDGE*&, double, double* clColor, double xRotate = 0);
void BuildKuenPipeFromWire(position& start, position& end, EDGE*& my_edge,
            double radius, double* clColor, ENTITY*& my_body);
void BuildKuen86Wire(double radius, double v, double* clColor, int nFlag=1, int nWireFlag=0, int nPlusFlag=0);

//projective functions
double FProjective1(double x, double y, double z, int);
double FProjective2(double x, double y, double z, int);
double FProjective3(double x, double y, double z, int);
void   BuildProjectiveWire(int nFlag, double radius);
void BuildCoil(..);
void BuildBone(..);
void BuildBaseWire(..);
```

5. Genetic algorithms and evolutionary models

Having become widely used for a broad range of optimisation problems in the last ten years, Genetic Algorithm has been described as a "search algorithm with some of the innovative flair of human search". Genetic Algorithms are today renowned for their ability to tackle a huge variety of optimisation problems (including discontinuous functions), for their consistent ability to provide excellent results and for their robustness. Natural evolution acts through large populations, which reproduce to generate new offspring that inherit some features of their parents (because of random crossover in the inherited chromosomes) and have some entirely new features (because of random mutation). Natural selection (the weakest creatures die, or at least do not reproduce as successfully as the stronger creatures) ensures that, on average, more successful populations are produced in each new generation than less successful ones.

Any evolutionary architectural models require architectural concepts to be described in the form of genetic codes. Then these codes are mutated and developed by computer programs into a series of models called populations. While models are evaluated by optimisation or selection sub-systems, the codes of successful models are constantly picked up until a particular stage of development process is reached.

In order to manipulate a complex model with a generative and evolutionary program it is necessary to define the followings: a genetic code script, rules for the development of the code, mapping of the code to a virtual model and, most importantly, the criteria for selection.

The representation of phenotypes is a fundamental element of any evolutionary system. In design applications, phenotypes represent designs, which formulate possible solutions to be evolved by the system. Moreover, phenotype representation plays a significant role in determining the size and complexity of the genotype. The two main 3D representation methods are surface representation (or boundary representation) and constructive solid geometry (CSG). The first method typically uses combinations of equations and control points to specify shapes, while CSG combines different primitive shapes to form more complex shapes. There is a third of the commonly used solid representation called spatial partitioning. This is to decompose a solid into a collection of smaller, adjoining, non-intersecting solids that are at lower primitive level than the original solid. There are a number of variations including: cell decomposition, spatial-occupancy enumeration, octrees, and binary space-partitioning trees.

Primarily, our model in this paper is the boundary representation model. In this representation, architectural envelopes are represented by mathematical data of the main model geometry. Changing the surfaces of a model is achieved through adding or subtracting mathematical data. In accordance with the mathematical functions type data, we use a cell division model. A cell division model is based on the structure of a living object. As in nature, the shape of a living object is constructed from the basic genetic information in the cells and organisms. The genotype contains information that is the basic construction unit of everything, called the chromosome. Chromosomes form proteins and other large molecules. Chains of molecules will form tissues and organisms to form the whole body. In a natural environment, development begins with the chromosome, which forms the base. Then a number of smaller cells are constructed. Large cells are resulted from joining and other operations and form a multi-cellular structure. In a word, the cell division models simple divide the whole process of involution into basic units and operations.

For a better description of the combination of functions, we use a jelly model as an example. This is a derivation of the cell model. A layer called the jelly layer is added to the model to represent a compound structure. We use this model to represent functions in various combinations. Basically, the model has three layers, that is, the gene layer, the cell layer and the jelly layer as shown in the next diagram.

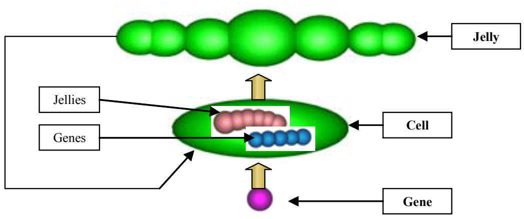

Fig 5.1 A jelly model

It is clear that the above model is like the molecular structure in biology. Jelly plays the role of a large molecule, and is composed of cells. In a cell, there are genes and other small molecules (jelly). The smallest unit in this chain is gene that forms the base of the three structures.

The second model in our system is the discrete model. The basic structures in this model are section and outline data structures. Each of these two outlines is an ordered set of double numbers, with auxiliary data indicating steps and size. To eliminate the discontinuities caused by the data structure, a mollifying operation is introduced.

Mollifying operations act as function smoothers. They can smooth a discontinuous function by substituting the value at one point by some average in a neighbourhood. In the one dimensional case, a mollifying operation is a non-negative, real-valued function $J \in C_0^\infty(R)$ such that

(i) $J(x) = 0$ if $|x| \geq 1$, and

(ii) $\int_R J(x)dx = 1$

An example of a mollifying operation is the following function:

$$J(x) = \begin{cases} ke^{-1/(1-|x|^2)}, & \text{if} \quad |x| < 1 \\ 0, & \text{if} \quad |x| \geq 1 \end{cases}$$

where

$$\frac{1}{k} = \int_{|x|<1} e^{-1/(1-|x|^2)} dx$$

Take $\varepsilon > 0$ and $J_\varepsilon(x) = \varepsilon^{-1} J\left(\frac{x}{\varepsilon}\right)$. Then the convolution

$$J_{\varepsilon^*}(x) = \int J_\varepsilon(x-y)u(y)dy$$

is the mollification of the function $u(x)$.

Finally, the discrete model can be illustrated as follows.

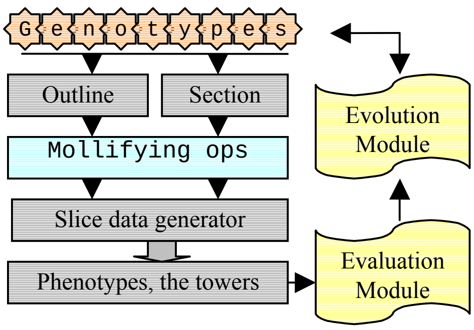

Fig 5.2 Discrete model

6. Multi-objective optimisation

In design systems, there are two main kinds of optimisation, that is, the artificial and automatic optimisation. Within the context of evolutionary design, the first class is usually called explorative evolution, which uses evolution as an explorer, not as an optimiser. In this case the optimisation process is controlled by human designers and the evolutionary system is used to help with the exploration of many possible solutions, so as to provide inspirations and to identify the range of useful solutions.

A modified version of this explorative evolution is an automatic process guided by natural selection defined as fitness function. By telling the computer the desired function in the form of a set of evaluation routines, but not anything about the design itself, the user is removed from the loop and the computer can find the final solutions to design problems. Therefore, a multi-objective optimisation function is needed in this process. Accordingly, the fitness functions must calculate appropriate information about the individual, and then use this information to calculate how well each individual satisfies particular criteria. In short, the fitness functions are a map from each individual to a point in high-dimensional Euclidean space. In this case, partial ordering is an effective method to represent relations of points. In this section we present two definitions in spaces with and without linear structure.

Definition 6.1 Let E be a set and Σ be a subset of $E\times E$. We will call the subset Σ a partial ordering provided that the following properties are satisfied.

(1) $(x,x)\in E\times E$, where $x\in E$.
(2) $(x,y)\in E\times E$, $(y,x)\in E\times E$ imply $x=y$.
(3) $(x,y)\in E\times E$, $(y,z)\in E\times E$ imply $(x,z)\in E\times E$.

Definition 6.2 Let E be a linear space and P is a nonempty convex set. We will call the set P a cone if the following properties are satisfied.

(1) If t is a nonnegative number and $x\in P$, then $tx\in P$.
(2) If $x\in P$, $-x\in P$, then $x=0$.

Cone is an important tool in the study of non-linear problems and positive solutions of differential equations. It is one the three main methodologies in modern non-linear analysis. In [7] the reader can find detailed theory of cone and applications. In general, most of the partial orderings in applications in analysis are derived from cones.

Let P be a cone. Define

$$x \le y \Leftrightarrow x - y \in P$$

Then it is easy to show that the above definition is a partial ordering. In partial ordering spaces, it is often convenient to define a metric. Then we can get a measurable property from a descriptive concept. We call such a measure the Hilbert projective distance. Let P be a cone, and E a partial ordering linear space, x, $y\in E$. If there are positive numbers t and s such that

$$x - ty \in P, \quad y - x/s \in P$$

Then from the definition of partial ordering we have

$$ty \le x \le sy$$

Now we define

$$M\left(\frac{x}{y}\right) = \inf\{\lambda > 0 : x \le \lambda y\} \quad , \quad m\left(\frac{x}{y}\right) = \sup\{\mu > 0 : \mu y \le x\}$$

Definition 6.3 We call the following function the Hilbert projective distance of the two points x, y:

$$\rho(x,y) = \ln M\left(\frac{x}{y}\right) - \ln m\left(\frac{x}{y}\right)$$

Similarly we call the next function be the Thompson distance of x, y:

$$d(x,y)=\ln\left(\max\left\{M\left(\frac{x}{y}\right),\quad M\left(\frac{y}{x}\right)\right\}\right)$$

Examples Now we consider a simple example. Let E be the linear space of n-dimensional vectors, and let P be the cone of points with non-negative elements, i.e., $x=(x_1,x_2,...,x_n)$ if and only if $x_1,x_2,...,x_n$ are non-negative. Let $x=(x_1,x_2,...,x_n)$ and $y=(y_1,y_2,...,y_n)$ be two points with $x_1,x_2,...,x_n>0$ and $y_1,y_2,...,y_n>0$. Then it is easy to compute that

$$m\left(\frac{x}{y}\right)=\min_i\frac{x_i}{y_i},\ M\left(\frac{x}{y}\right)=\max_i\frac{x_i}{y_i}$$

Thus we get the two new distances as follows.

$$\rho(x,y)=\ln\left\{\max_{i,j}\frac{x_i y_i}{x_j y_i}\right\},\quad d(x,y)=\ln\left(\max_{i,j}\left\{\frac{x_i}{y_i},\frac{y_j}{x_j}\right\}\right)$$

For general purposes, we give another definition of metric induced by a partial ordering.

Definition 6.4 We call the following function F-projective distance of the two points x, y:

$$\rho_F(x,y)=F\left(M\left(\frac{x}{y}\right),M\left(\frac{y}{x}\right),m\left(\frac{x}{y}\right),m\left(\frac{y}{x}\right)\right)$$

where F(a,b,c,d) is a function.

Now we describe a multi-objective optimisation scheme based on partial ordering technique. In design problems, we always use genotypes and phenotypes to denote two forms of a design solution. Genotypes will construct a space called *genospace*. We say one design is better than another design by saying that the phenotype of one design solution is better in some aspects than the second design solution. These better characteristics will correspond to some comparison principles of their genotypes. Of cause, there will be a number of such principles and they form a principle set. We will call the principle set *compatible* if we can say definitely one is better than the other. That is, if there are two genotypes *x* and *y*, and *x* is better than *y* while *y* is better than *x*, then *x* is equal to *y*. We will always consider compatible principle set.

Definition 6.5 Let the genospace be G and denote the comparison principle set by P. Define a partial ordering in G by principles in P. That is, $x\le y$ if and only if *y* is better than *x*.

Because the principle set is compatible, we see that the relation $x\le y$ is a partial ordering. Moreover, when the genospace is linear, we can obtain a cone by the principle set. This is possible when the genotypes are real vectors and they form a continuous region. Now we recall a famous lemma in set theory, the Zorn's Lemma. It tells that in a partial ordering space, if every totally ordering subset has an upper bound, then there is a maximal element. Interpreting this lemma in terms of design optimisation, we say that when we can get a best design from a series of design solutions, which have the property that if one design is better than the previous design, then we can get an optimal design in this direction. Thus we conclude with a proposition based on these definitions.

Proposition 6.1 There is an optimal design solution in any direction in a multi-objective design problem, provided that we can get a best design from a series of design solutions which have the property that one design is better than others.

This part of research is still on going and we expect to use more real design examples to verify these definitions and proposition.

7. System implementation and applications

Based on the theory described above, we have implemented a system based on 3D solid modelling techniques. Two integrated design studio environments have been integrated in this system. The platform is personal computers under windows 2000 or windows XP of Microsoft. The programming languages include Microsoft Visual C++ version 6.0, ACIS 3D Kernel, MatLab™ version 6.1 of MathWorks™, Inventor version 5 for additional solid modification. One of the features of the system is that all the sub-systems are fully compatible with commercial CAAD tools and systems, as well as rapid prototype facilities. A large number of object-oriented components of sophisticated surfaces and envelopes have been built using evolutionary techniques and partial ordering theory. Computational mechanisms have also been developed with which these basic data structures and components can be visualised, combined or split to allow new data structures or new forms to be derived using generative techniques. We are also exploring the possibility to scale up the applications with potentially thousands of solid objects with textual and spatial design details in our Global Virtual Design Studio powered by high performance computer and multiple VR projection facilities.

The first part of the system we have implemented is named as TowerDev. This is a fully controllable solid modelling environment with non-linear transform of existing solid models into design prototypes. The environment consists of an ACIS SAT viewer; Fly through viewer; Colouring and Rendering; and Programmable design routines for architectural envelopes. The main user interface of this part of the system is as follows:

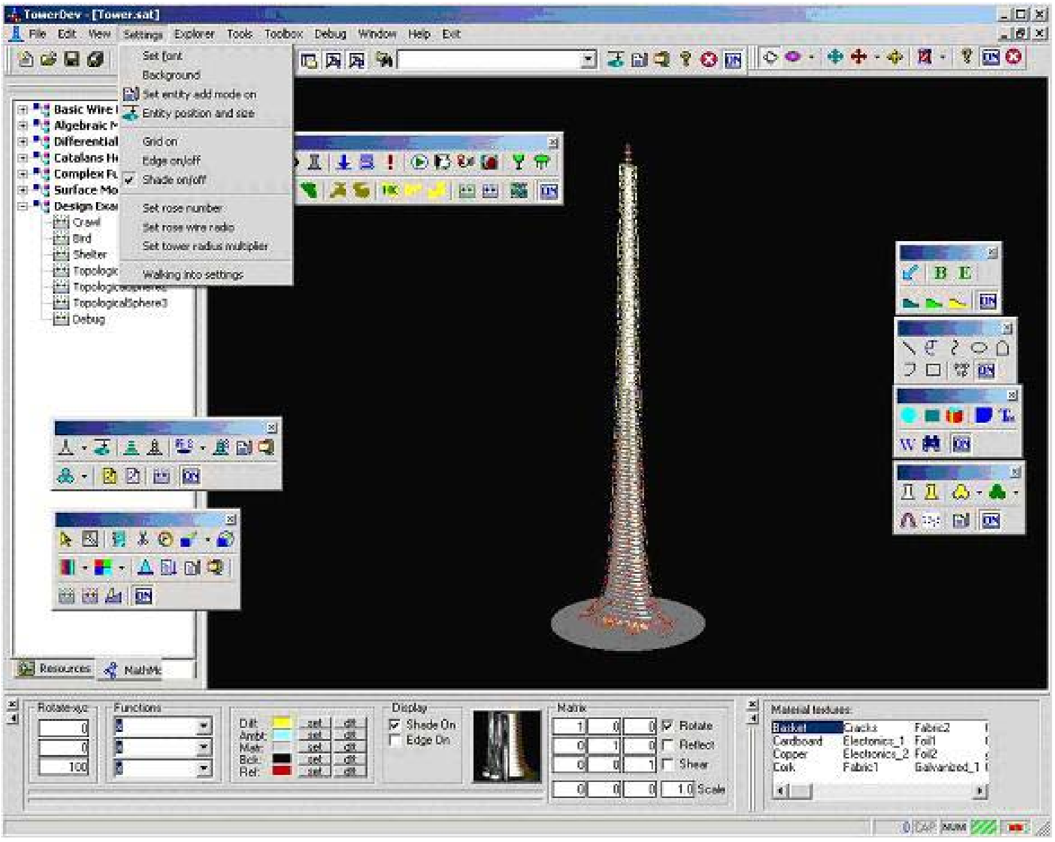

Fig 7.1 Graphical user interface of the system

Some design examples created by this system are illustrated as follows:

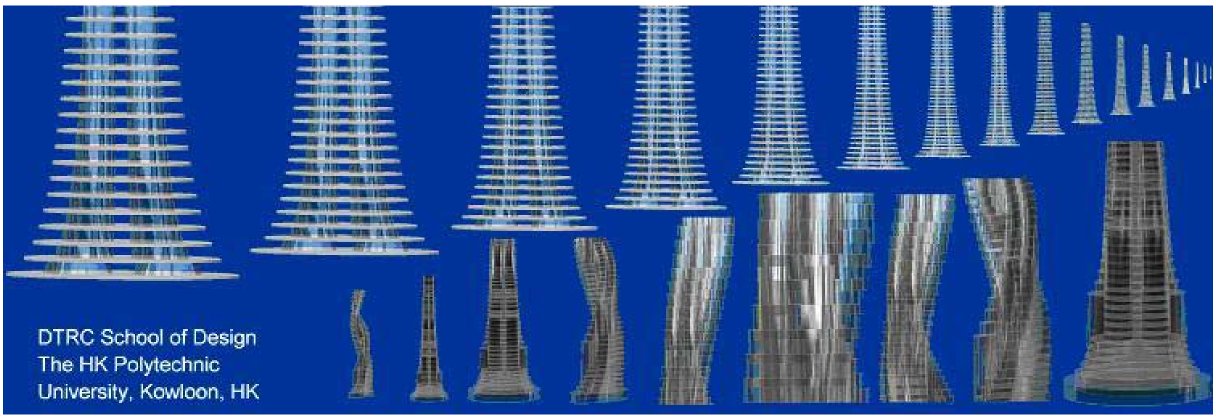

Fig 7.2 The variety of tower structures

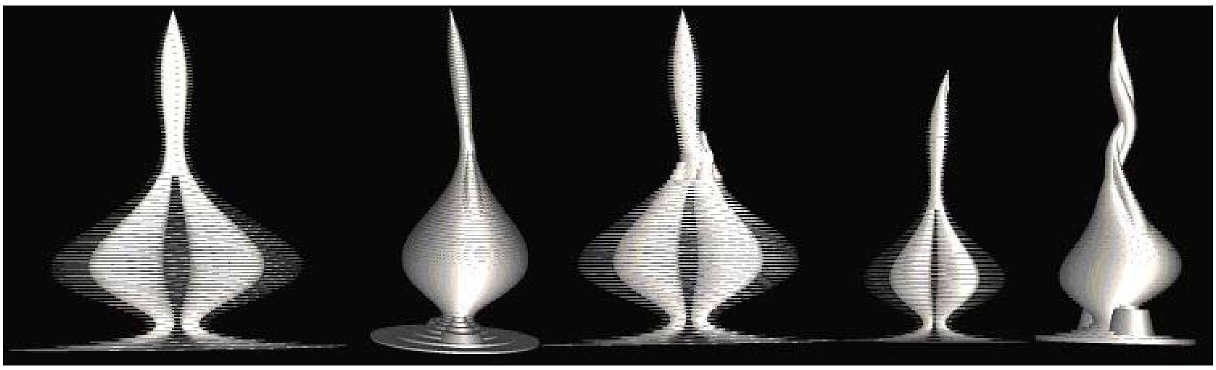

Fig 7.3 Models generated by functional envelopes

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CREATIVE MULTI MEDIA: THE COMMODITY OF THE 21ST CENTURY

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Abstract

The Digital Revolution has turned individuals, institutions, and businesses into a new form of collective wealth and prosperity. This revolution has effected a creativity burst that goes far beyond an increase in the number of those involved in design tasks and challenges, in both professional and amateur settings. The Internet in particular are not only distributing media but most importantly it is a reference platform in which ideas, talents and capabilities emerge and are refined, enhanced and perfected through the inspiring interplay of collaboration and competition.

This paper briefly examines the relationship between art and science through the ages, discusses their recent re-convergence, and examines their current relationship via real world applications and productions. The study of such productions, their successes and the impact they have had in the marketplace based on designs and aesthetics instead of advanced technology appear to support the argument. It also highlights the need for accelerating this process and suggests that the re-convergence is a result of new technologies adopted by practitioners that include the effective visualisation and communication of ideas and concepts. These elements are widely found today in multimedia, which offers increased power and new abilities to both scientists and designers.

This paper also highlights the need for the employment of emerging computer-based interactive technologies which will enhance the design process, better decision-making, increase the quality of communication and collaboration, lessen the errors and reduce the design cycles. A Multimedia Palette is proposed as a design platform to expose one's imagination, creative and innovative ideas, and provide a richer and more creative multimedia content design and development. Following encouraging first round results, an expanded version of the suggested platform has been experimented in the Faculty of Creative Multimedia, Multimedia University for the last 5 years, in integrating design and computer skills in the teaching and learning projects.

Keywords: creativity, re-convergence, Multimedia Palette, Creative Multimedia

1.0 Introduction

According to Bronowski [1], science and art were originally two faces of the same human creativity. However, as civilisation advances and works became specialised, the dichotomy of science and art gradually became apparent. Hence scientists and artists were born, and began to develop works that were polar opposites. The sense of beauty itself became separated from science and was confined within the field of art. This dichotomy existed through mankind's efforts in advancing civilisation to its present state.

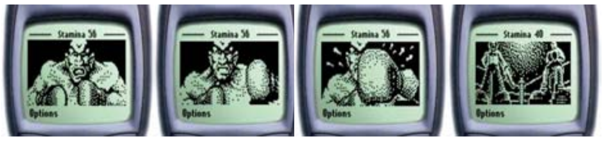
Mayall [2] has studied the reconciliation of art, science and technology in design. He draws distinctions between the mathematical engineer who creates new devices mainly through the alliance of specifications and working drawings, and designers interested in the form for whom it '... was a matter of observing what they regarded as proper combinations of forms and colours'. Stewart [3] highlights the contrasts that exist between what is inspired to what is formal and what is practical to what is academic and at the same time emphasising the need for a contingency approach to design.

The challenge for us is to find appropriate means and effective ways to integrate the arts and the sciences and reduce the gap between the two domains. This paper will study briefly on design creativity and the media that have the potential to accelerate the process of re-convergence of arts and sciences, particularly in multimedia and virtual environments, as we try to make a bold leap into the future in the Multimedia Super Corridor (MSC). As our country's main goal is to move into a new 'knowledge-based' economy (k-economy), the ability to be creative in accelerating the re-convergence efficiently and innovatively will be the key to our success. A few case studies that have adopted multimedia technology successfully will be presented.

2.0 Creativity in Design

According to Lawson [4], while we have seen that both convergent and divergent thought are needed by both scientists and artists, it is probably the designer who needs the two skills in the most equal proportions. He further argues that designers must solve externally imposed problems, satisfy the needs of others and create beautiful objects. In this competitive world, one could argue should creativity in design need to be original? According to Robert Venturi, [5] for a designer**,** it is better to be good than to be original. Richard Seymour, one of the leading product designers**,** considers good design as a result of the unexpectedly relevant solution not wackiness parading as originality. Mr. Idei, the CEO of Sony Corporation, Japan points out that all designers should be motivated to function as an ace pitcher with every product [6]. What can be learned from these is that Venturi, Seymour and Idei are more critical and cautious on the function than totally on the originality of the design.

Creativity is concerned with the design of products that in some ways offer added value and functionality when compared to products or ways that have preceded them [7]. Even applying the convergence of technology, new innovation often failed due mainly to minimal awareness of the context. For example, when WAP (Wireless Application Protocol) technology was introduced, almost every single games company expressed an interest to further develop in existing cellular products or devices but then dismissed the idea [8]. There was no serious effort to search for design within the WAP constraints and wireless communication capabilities. In contrast with Firesoft's approach, they first searched on the WAP standard and relevant cellular technology to better understand the medium. Their design was based on these constraints to deliver original product and interface design (i.e. via Burgundy WAP server environment) for effective and richer content development. The recent revolution in business nowadays refers to the change through creativity which includes ISO 9000, total quality management, re-design and re-engineering, as usual responses of Western companies waking up to the competition from Japan (figure 1).



W@P Boxing

W@P Derby Day

W@P Dungeon 3D

W@P Kingdom of the Nile

Figure 1: WAP game samples

Design, in nature is an interdisciplinary activity that requires a collective input from different skill sets of professional, layman (clients) and specialist. Lawson [9] believes that good design is often a matter of integration. It is a powerful tool and allows designers to shape their products and environments in a way that may affect the well being of people in general, especially in the global networked economies. Papanek [10] defines design as a function complex where Method, Use, Need, Telesis, Association and Aesthetics all are strongly related to Functionality. Pugh [11] rightly argues that design is central to business success and, for that to happen, it has to successfully interact with the various business facets.

For example, the release of *Computer Space* into amusement arcades in 1971 marked a beginning in the commercial electronic games market and accelerated the overall growth in the late 1990s that surpassed the film industry in revenues. According to the USA-based Interactive Digital Software Association (IDSA, 1998) the games industry reached "…$16 billion in economic activity in 1997, not including computer and video game hardware sales" [12]. Rollings and Morris [13] have studied 'the best practices for game design and programming' and have concluded that most of the works behind development lies in design. Game [14] and game development [15] now encompasses the fields of real-time computer graphics, prototyping, visualisation, art, animation, and content creation. It has entered new fields such as immersion, applied artificial intelligence, physical-based modelling and real-time communications using the Internet as a method for delivering content.

3.0 Creativity in Design Communication

As the world becomes border-less or hyper-competitive [16] in nature, the need to communicate becomes paramount. New tools provide us with a totally new way of communicating. New multimedia tools can be defined as an integrative medium, which appeals to all five human senses. However the abuse of tools for communication is already happening. How many times have we seen or heard an interesting introduction or presentation only to be left asking, yes, but what does it mean? What is it exactly? In looking for tools, the solution lies partly in finding the tools to help you define the problem. But the bottom line is what are you trying to communicate? Multimedia, like any other communication tools, must be seen as a mean rather than an end.

One of the most powerful vehicles to competent design is the efficient communication of concepts and values between individuals involved in the design, marketing, manufacturing and use of a product from concept to delivery [17]. Communicating these concepts to individuals in the design teams and user groups is a challenge. Team synthesis and synergies are needed to broaden communication, control the design process and aid decision making. Such synergies also work against certain creativity or other individuals that in some cases choose to express themselves egocentrically at the expense of other team members and ultimately the customer. Pugh [18] has shown that linking mechanisms work better when different units are arranged organically rather than mechanistically and stated a number of requirements to enhance communication within the design environment. These include a relaxed working atmosphere, open communication, interpersonal trust, the autonomy of the individual, participation and the provision of opportunities for individuals to exercise their expertise [19].

4.0 Creativity in Design Computing

The designing of computer tools that will benefit design per say are tools that the complexity of their domain does not interfere with the design process [20]. Poor tool design forces designers to deal with complexities that exist in the wrong domain that subsequently lead to compromise or poor designs and products. A good example of this is the success that Apple Macintosh enjoyed during the middle and late 80s by offering an intuitive way in which text and graphics were manipulated and viewed on the screen. This was in contrast with the text-based interfaces (offered by competing products on the IBM PC and other desktop machines during that period). Graphical browsers and front-end interfaces will increasingly act as access points to information and its visualisation [21], educational material, software applications and on-line collaboration. Current and emerging Virtual Environment (VE) and Multimedia technologies link the two areas of information and visualisation together making an otherwise complex content accessible to wider audiences.

One of the creative achievements in design computing is the Internet. Some have defined the Internet as an 'electronic courier' service and its integration with multimedia is already happening. We can all agree that the advantage of the Internet is that for the first time, users, no matter where they are, have access to a wealth of information, which is not available to past generations. However, this can also be dangerous. In our enthusiasm to make use of the labyrinth network of information, there is a tendency to use the Internet as a starting point and give users access to all the information. The wide acceptance and adoption of Internet technologies by organisations and individuals of different backgrounds demand for good information design practices to be adopted that will facilitate information storage, education, collective learning and most important fast retrieval and effective delivery [22]. The sharing and exchange of information in all its facets allow teams and companies to capitalise on their intellectual assets and expertise in a global scale. Companies that more thoroughly understand, and take advantage of new networked resources are going to establish a competitive advantage. Small [23] [24] and large corporations (e.g. Chrysler's Extended Enterprise and Sony Corporation) have shown that they can lead in the information age and define the state of the art in developing and adopting new practices to gain a competitive advantage in emerging global networked economies.

Competitors will no longer be disadvantaged by the location of their business or traditional distribution channels. Linux a non-profit making community grew to thousands of people from all over the world, working together and without the aid of managers, managed to turn Linux into one of the best versions of UNIX ever designed and developed [25]. These information and knowledge dissemination networks have given these companies a competitive advantage in the way they design their operations, products and distribution of services. For Sony Corporation, the new kind of computing environment will rely on the technology called Jini (pronounced JEEN-ee), developed by Sun Microsystem [26]. It is based on the concept that devices should work together in which it connects to this collection (e.g. television, audio equipment, digital camera and computer) or network of services by plugging it in, with no drivers to find and no operating system to start or restart.

5.0 Creative Multimedia

Creative Multimedia is much to do with content design. We can define the word content as the substance or material that will give (a product) a distinct form or character [27]. Multimedia can be described as a new medium that will enable diverse content of audio-visual images including computer graphics, animation, sound and text, to be sent out as seamless digital media. It has the underlying potential to integrate the traditional methods of expression to cultivate new activities appropriate for the new era. These methods of expression are diversified, ranging from packaged works for both non-interactive and interactive, installation, network style works and Virtual Reality style works. The integration of arts and science through multimedia that will allow us to overcome problems that neither art nor science alone can solve. The scientist needs the insight of the artist; the artist needs the logic and technical skills of the scientist. Since both science and art were from the beginning closely bound together in the human instinct to survive, they can be reunited (designers). Multimedia does (or does not) mean a lot of media. We believe that multimedia means the multiple ways that you can look at ideas to find relationships in your own unique or creative way (and time). And the fact is there is a lot of different media forms that can express or illustrate this idea for you. It might be straight video, or audio, or text, or a combination, or graphics or slide-shows.

The announcement to develop a national information infrastructure in the early 90's has sparked a global use of information and communication technology (ICT) in developing countries particularly Asia (i.e. Philippines, Thailand, South Korea, Singapore and Malaysia) that integrates features of Internet, Cable TV, Satellite and Telecommunication. For Malaysia, the Multimedia Super Corridor (MSC) initiatives have opened up the country to local and world-wide investments in areas such as education, research and development, new business venture and working opportunities, besides posing as the 'digital divide' between developed and developing countries. The biggest challenge for the MSC is not just to embrace technology but also to create contents that are relevant to our society and world at large. Creating not just the right environment but also a challenging one to stimulate creativity, must be our priority. This clear vision and objective will ensure that these creative talents can function and excel in the content that they produce. Eventually, the challenge for us is to develop a critical mass of talents, whereby content creation are undertaken not just by inventors but by the users themselves. In order to take the challenge, The Faculty of Creative Multimedia has proposed Palette of Wonders (POW) [28] as a multimedia design platform that exposes creative and innovative ideas to suit the real need of specific users. It focuses on the nature of multimedia, which consist of three different stacks namely multimedia principles, elements and characteristics (figure 2).

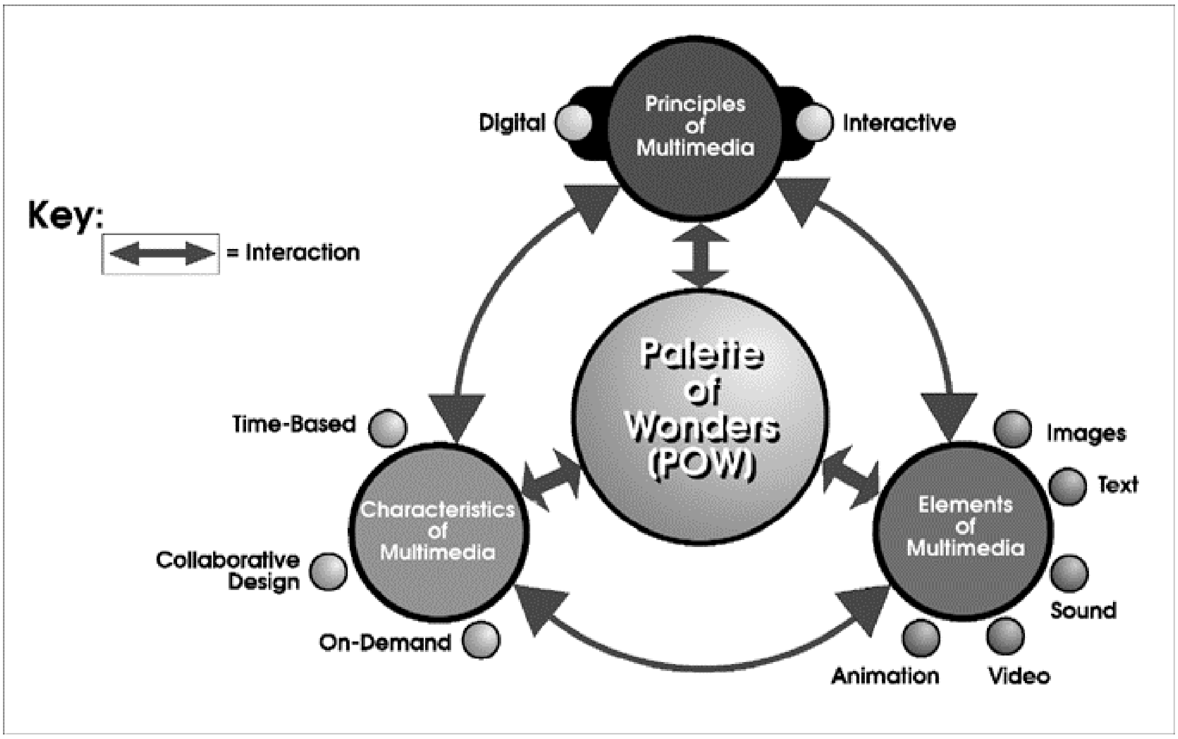


Figure 2: Palette of Wonders [POW]

5.1 Stack 1 - Principles of Multimedia

We believe that multimedia is established on the principles of being digital and interactive [29]. This paradigm shift (i.e. moving from analogue or conventional to digital technologies) has fuelled the convergence of different industries today. Without this combination, the content remains similar to analogue value of which many developers have failed (i.e. creating digital content with full of analogue qualities or passiveness) in contributing to the paradigm shift. With interactivity embedded into multimedia content, it enables the user to a certain degree to control and acquire information. Designers have the ability to experiment and explore elements of multimedia in the form of text, image, sound, video and animation in developing the content. Never before has designers had the ability to mix and match different media types into one coherent application (i.e. digital format) to convey information.

5.2 Stack 2 - Elements of Multimedia

The second stack represents the elements of multimedia namely text, image, sound, video and animation or better known as the 'spice'. Never before has designers had the ability to mix and match different media types into one coherent application to convey information. This posses a new challenge to designers as they have to incorporate the different media mix to express their ideas. With the availability of multimedia authoring tools, these different digital media can be arranged and designed according to the designer's needs and intentions. This is possible as the format in which these media exist is in one common format, that is the digital format. As content designers, their task is to constantly place a " fresh face" on top of information technology.

5.3 Stack 3 - Characteristics of Multimedia

At the most basic level, a combination of stack 1 and 2 is sufficient to create multimedia content. However, it is suggested that with the adaptation of multimedia characteristics the content will be significant in terms of effective use, marketability, and impact on individual application. This can be identified as time-based, collaborative and on-demand. Since in our daily lives we are used to motion-based situation (e.g. televisions or movies), it is suggested that multimedia designers consider this as one of the key features that easily relates to perception, and thinking attributes. The availability of the Internet could be an advantage to prepare a ‘collaborative’ design society and platform for discussion, decision-making, cross-referencing, linking, retrieving, and data distribution. Because of the complexity of design and demand from specific user and application, multimedia content design should give priority to only on-demand design solution that could be developed such as in the form of data-dependent, and video/audio streaming behaviours.

Early encouraging results are demonstrated in our classes online and students content design portfolio. The expanded version of the suggested platform was originally developed by the Faculty of Creative Multimedia, Multimedia University and has been implemented in the design of the ‘i-Putra’ portal (http;//www.i-putra.com.my) together with one of the local content developers (I-Design Sendrian Berhad). It is basically a digital softcity of Malaysia’s new administrative capital, Putrajaya. It is designed to be fully interactive channel of content, context, community and commerce for the user to search, explore, and venture business to support the intelligent city requirement (figure 3).

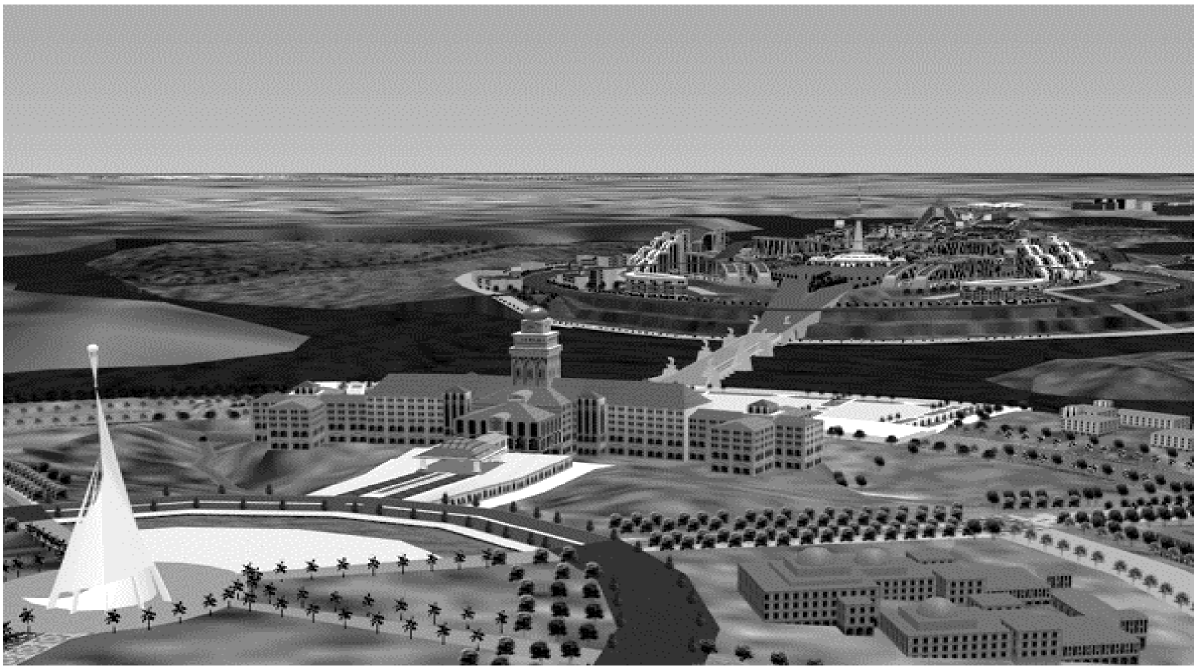


Figure 3: An aerial view shot of Putrajaya real-time simulation (courtesy of Faculty of Creative Multimedia, Multimedia University, Malaysia, 2001)

6.0 Conclusion

Content development particularly creative multimedia is believed to be one of the most demanding skills set needed in the 21st Century due to the ability and power to change the way we think, work, produce, act on, innovate and do business. We see multimedia tools as being the common denominator to integrate the sciences and the arts and to accelerate the process of re-convergence in order to reduce the gap for effective and meaningful results. As individual becomes groups, and groups become communities, and communities become villages, and villages become nations, the critically scarce resources that need to be conserve in the future is the creativity of users of these tools.

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CAD – The Creative Side
An educational experiment that aims at changing students' attitude

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Abstract

The present paper describes an innovative design education system tried out at two different architecture schools in Brazil, with opposite approaches to the use of CAD. The experimental courses had two main goals: (1) to explore the use of logical operations in design, such as symmetry, recursion, parameterization, and combinatorial analysis, and (2) to apply these techniques with the use of the computers, using CAD not only as a representational tool, but rather as an explorative, customizable and programmable design aide for the creative process. The experiments resulted in a number of interesting compositions, design projects and programs, and assessment questionnaires revealed a real change in students' attitude towards the use of CAD in architecture. The experiments related were the field research part of a Ph.D. thesis defended at MIT in July 2002.

The present work had the support of CNPq, a Brazilian entity devoted to the scientific and technological development.

1. Introduction

In the last forty years of CAD development, the original purposes of Computer Aided Design have almost been lost. Nowadays its use in architecture is practically restricted to drafting and representation, with little emphasis on the design process. Mitchell (1990) identifies an inflection point in CAD history with its popularization in the 80's, targeting the emergent PC market, and suggests that at after that point "the wider possibilities were largely ignored"(p. 483). In fact, with the standardization of CAD packages, they were turned into drafting versions of word-processing software. As a consequence we end up using an extremely powerful machine below its capacities, and keep doing repetitive tasks while we could make better use of our time. Most of all, we waste the possibilities of finding new shapes with the help of complex computations, which are impossible to envision when working by hand.

The present paper describes two experimental instances of an innovative CAD education system developed as a Ph.D. thesis for the Design & Computation program at MIT's School of Architecture and Planning. The system's approach is similar to Mitchell, Ligget and Kvan's in *The art of computer graphics programming* (1987) and is inspired by Stiny's theory of shape grammars (1975). It is based on six topics from computational design, put into practice through a series of exercises that include using a CAD's standard commands and programming to create new design environments. The six topics - symmetry, recursion, parametric shapes, shape generation, algorithmization of design processes and emergent shapes - consist of overlapping, inter-related concepts that reinforce the understanding of the computational aspects of design. For example, symmetry can be generated through the recursive application of a design rule, while the generation of design alternatives can be obtained after the parameterization of a shape and the substitution of its variables by ranges of values within the problem's constraints.

2. Context

The present experiment has been conducted in two top-ranking architecture schools in Brazil: the School of Architecture and Planning at the University of São Paulo (FAU-USP), which became independent from the engineering school in the late 60's, and the recently founded architecture course of the School of Civil Engineering at the University of São Paulo at Campinas (FEC-UNICAMP). While the former has shown a peculiar resistance to the inclusion of computer-based tools for architecture, the later has incorporated IT subjects in its curriculum since its very beginning. While FEC-UNICAMP has mandatory CAD courses from the very first semester, at FAU-USP the only two subjects offered are elective courses with limited enrollment, usually attended by students from upper grades. Despite that difference, in both schools the IT subjects focus on the use of the computer as a representational tool.

The CAD software used in both cases was AutoCAD 2000 ADT, which includes an interactive VBA development environment. The group of students attending the experimental course at FAU consisted of 19 undergraduate architecture students, all of them with some prior experience in AutoCAD, but none with prior experience in VBA programming. At UNICAMP, the group attending the experimental course consisted of 7 undergraduate architecture students, 6 undergraduate civil engineering students, 4 architecture graduate students and 2 professional architects, all of whom with some prior experience in AutoCAD, but also none with prior experience in VBA, although the undergraduate engineering students had some prior experience with other programming languages.

The course at FAU-USP happened as a series of 6 weekly sessions during a school semester , while at UNICAMP it was taught as a Summer course with daily meetings for two weeks. In both cases, the course materials were grouped under web sites, which included course readings, directions to exercises, technical instructions, lectures' slides and downloadable programs (see http://web.mit.edu/celani/www/fau/index.htm and http://web.mit.edu/celani/www/unicamp/index.htm). Besides, as the courses evolved, all the exercises presented by students were gradatively incorporated to the web site for classroom review. The two courses happened during the first semester of 2002.

3. Course description

In both cases, each session started with a lecture in which concepts were presented and buildings from the architectural repertoire were analyzed in terms of each concept. The second part of the sessions was always used for classroom exercises. Students were also given a number of reading materials related to each topic, which offered a theoretical support to the course.

For the first topic (Symmetry), students used AutoCAD's commands in a innovative way. With the use of multiple, dynamically updated views of the design space, students were able to design symmetric patterns in an environment that emphasized the whole instead of the units. During the study of topic 2 (Recursion), exercises were based on the use of Recursion Assistant (Figure 1), a VBA application especially developed for the courses. In topics 3 through 5 (Parameters, Generation and search and Algorithmization), small programs that incorporated each theoretical concept were first presented and used by students, then thoroughly explained, and finally modified by them. VBA programming was introduced in these 3 sessions, starting with the explanation of simple, pedagogical, sample programs, and the concepts behind them. In topic 6 (Emergent shapes) students started by generating 2D and 3D rule-based compositions with Recursion Assistant and then used standard CAD commands to perform Boolean operations on them, unveiling novel shapes.

Due to time constraints, only at FEC-UNICAMP students were asked to develop a final project, most of which consisted of VBA programs for automating design procedures or modeling parameterized versions of existing buildings. At FAU-USP, on the other hand, students were asked to develop small architectural design exercises as homework after each weekly session.

4. Results

The results of the two experimental courses was an impressive number of beautiful compositions and thoughtful programs. The exercises presented could be separated in five categories:

- Creative abstract compositions based on symmetry, recursion, parameterization and emergence (Figures 2 through 5).
- Small programs developed as tutorial exercises. Although these were in general not particularly creative, some students were able to propose interesting variations of the programs suggested, such as those in Figure 6.
- Images of architectural examples of symmetry, recursion and parametric shapes brought to class by students as a research homework, which provided a clue to how well students were assimilating the concepts introduced in each session.
- Architectural design exercises based on symmetry, recursion, parameterization and emergence, only at FAU-USP (Figure 7).
- Free-style final projects, only at FEC-UNICAMP (Figure 8).

Most of the final projects presented at FEC-UNICAMP consisted of VBA applications for different purposes, such as an automatic layout generator (based on a program provided in the course), an alternative generator for land-use, a stair-case 3D model generator, and programs for generating parametric versions of buildings by Brazilian architect Oscar Niemeyer. One of the best final projects was presented by an M.Sc. student with a background in architecture, who compared two designs by American architect Frank Lloyd Wright (a church and a synagogue) and developed a program to model both using the same algorithm, but taking different parameters (Figure 8). This student was able to analyze the two buildings from a computational point of view, understand and relate their geometric construction processes, and generate a common, parameterized description of both.

5. Discussion

The careful analysis of the exercises presented allowed to demonstrate students' understanding of the design environments and the concepts introduced in the educational experiments described above. Those exercises allowed students to put into practice the computational design theories learned, using techniques and resources at their reach. The two case studies proved also that the proposed system is flexible enough to be applied in different formats and for different background students, even when they are mixed in the same group, which was the case at UNICAMP.

Assessment questionnaires showed how the courses were successful in changing students' attitude towards CAD. Most students reported how they used to see CAD simply as a representation tool and how they started seeing it as a real design aide after the course. Although most students were not able to immediately apply what they learned in the experimental courses in studio subjects – which was due to different constraints, such as the unavailability of computers in the classrooms – they reported a strong conceptual influence to their design work. This shows how a shift in the way CAD is taught can also serve as an opportunity to introduce computational concepts in design education.

A comparison between the level of achievement of students with different technical skills was possible because of the different emphasis given to CAD at UNICAMP and FAU-USP. Apparently, the less familiar students were with CAD software, the harder it was for them to start seeing new possibilities in the use of computers in design. FAU-USP students, in general less skilled in CAD, often complained when they were asked to develop small programs in VBA, while UNICAMP students were more open to learning the new technique. For that reason a more philosophical approach was tried at FAU-USP and students were asked to develop architectural design projects using the concepts learned, instead of focusing too much in the programs. At UNICAMP, on the other hand, developing an architectural design project was one of the suggested themes for the final project, and yet none of the students – either architects or engineers – chose that way. All of them wanted to develop their own programs (except for an engineer who made an interesting computational interpretation of the work of Italian/Brazilian painter Alfredo Volpi).

A few unexpected observations could also be made during the two experimental courses, such as the efficacy of the two different formats. The summer course's compact format was probably more effective in terms of the assimilation of the technical contents, especially the programming language. In the more extensive format tried at FAU-USP, students seemed to forget the technical details learned from one week to the other, although they probably had more time to reflect on what was being presented at the conceptual level.

Although the results of the experiments described above cannot be over-generalized, they provide a preliminary conclusion of what kind of response can be expected from students in similar contexts. A deeper understanding of how CAD-implemented computational design education may influence the quality of designs produced by students is the next step in the research, but one that will demand a longer observation time and a close collaboration of studio instructors.

6. Acknowledgements

I would like to thank Professor Doris Kowaltowski from UNICAMP and Prof. Marcelo Giacaglia, from FAU-USP, for providing me with the opportunity to test my experimental course with their students. I would also like to thank all of the students listed below for participating in the experimental courses and contributing to my research with their talent and enthusiasm. Finally, I would like to thank CNPq, the Brazilian National Council for Scientific and Technologic Development, for funding this research.

7. List of students*

UNICAMP: Amanda Pietro Petter, Ana Lúcia Harris, Ana Maria Monteiro, Christian Dittz, Daniel da Rocha, Daniel Moreira, Fernando Basilio, Fernando Ribeiro, Gabrielle Damaso, Giovana Bianchi, Lauro Luiz Fco Fo, Livia Carvalho Berriel, Marina Otaviano, Patrícia Dias Falcão, Paula Roberta Baratella, Roberto Itapura, Sérgio Luiz Montagner, Wanessa Watrin.

FAU-USP: Ana Carolina Salomao, Chen Chih Cheng, Daniela da Costa, Daniela Vaz, Fabio Augusto Bellini, Fernando Vargas, Juliana Beividas, Laila de Andrade, Leandro Robles, Marcelo Nakazaki, Marcos Machado, Min Kyung Lee, Renata Figueiredo, Rodrigo de Azevedo, Stella Tomiyoshi, Thiago Lessa.

* Only the students who authorized the publishing of their names are cited here.

8. Figures

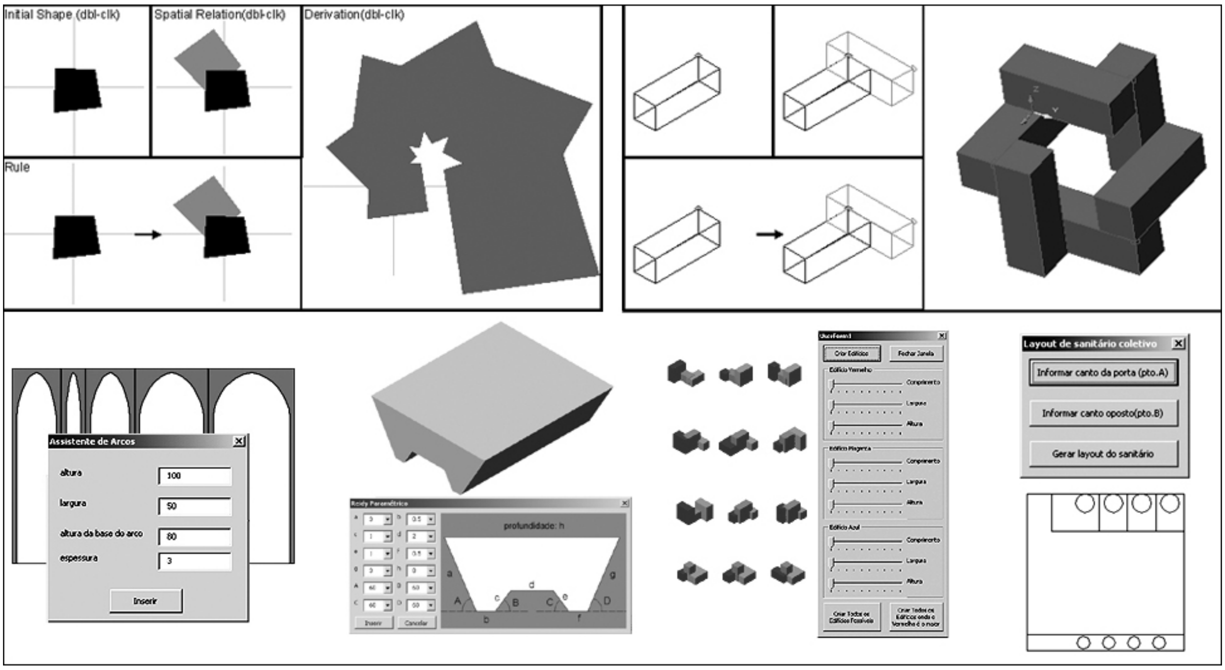

Figure 1: **VBA applications** especially developed for the experimental courses: 2D and 3D Recursion Assistant, Parametric Arches Assistant, Modernist Profile Assistant, Alternative Generator and Bathroom Layout Generator.

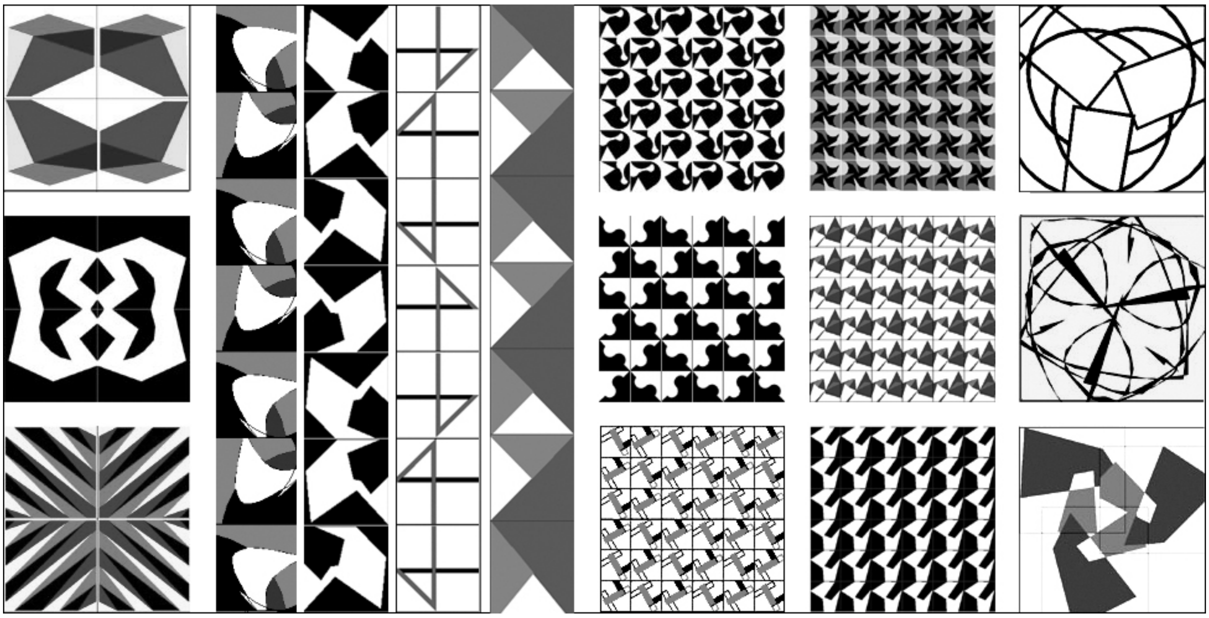

Figure 2: **Symmetry** exercises: **bilateral** (from top to bottom, left to right: Marcelo Nakazaki, Leandro Robles, Marcos Machado), **frieze** (Renata Figueiredo, Daniela Costa, Min Lee, Marcelo Nakazaki), **wall-paper** (Flávio Tanabe, Daniela Vaz, Renata Figueiredo, Daniel Rocha, Gabrielle Damaso, Marina Otaviano) and **cyclic** (Fernando Mello, Chen Cheng, Marcos Machado).

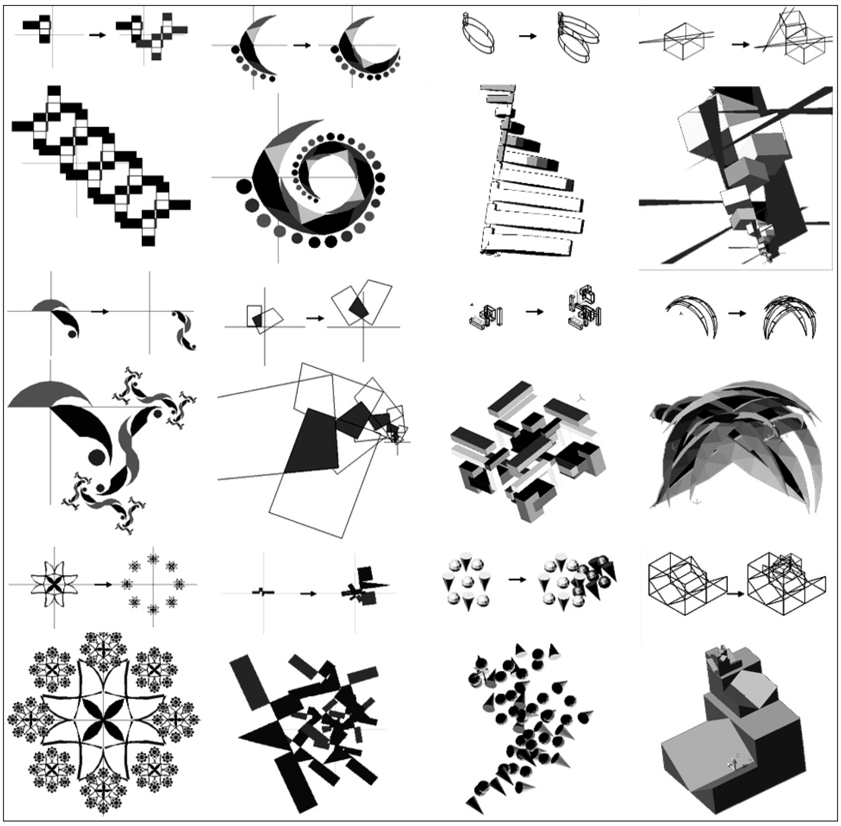

Figure 3: **Recursion** exercises: **2D** (from top to bottom, left to right: Renata Figueiredo, Núbia Bernardi, Gabrielle Damaso, Giovana Bianchi, Daniel Rocha, Fábio Bellini) and **3D** (Fernando Basilio, Marina Otaviano, Fernando Ribeiro, Ana Goes, Daniel Moreira, Gabrielle Damaso).

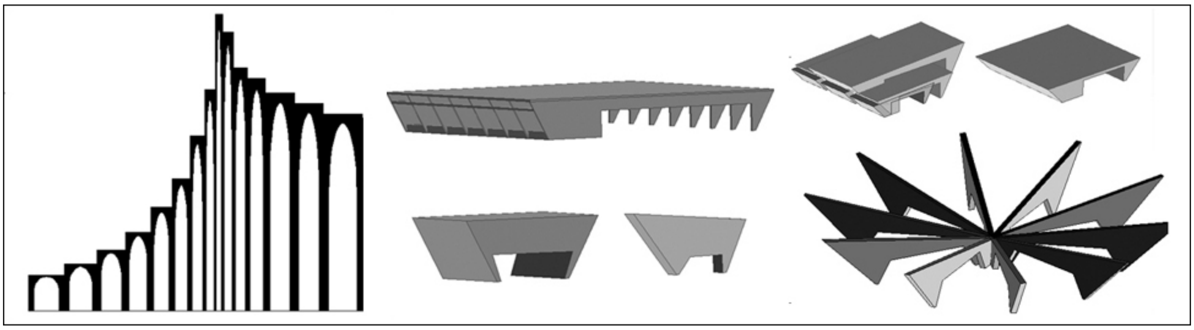

Figure 4: **Parameterization** exercises (Fábio Bellini, Marina Otaviano , Paula Baratella,).

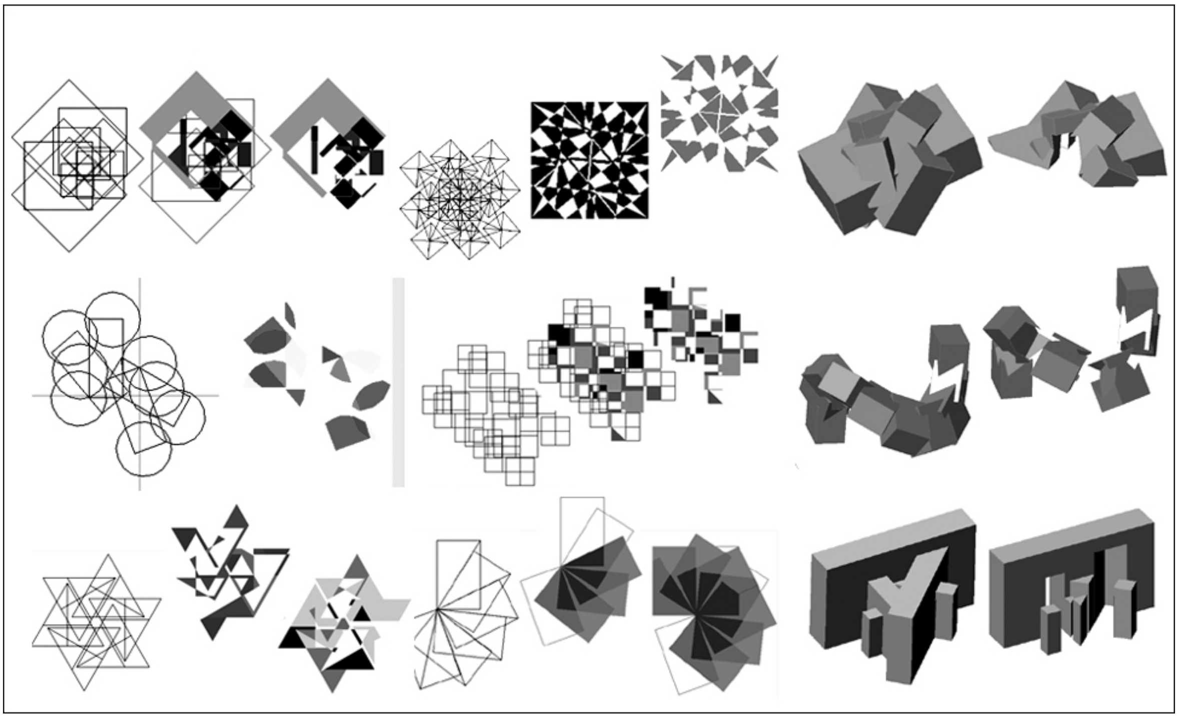

Figure 5: **Emergence** exercises: **2D** (top to bottom, left to right: Fernando Basilio Renata Figueiredo, Fernando Basilio, Gabrielle Damaso, Alessandra Arenales, Daniel Moreira) and **3D** (Stella Tomiyoshi, Fábio Bellini, Leandro Robles).

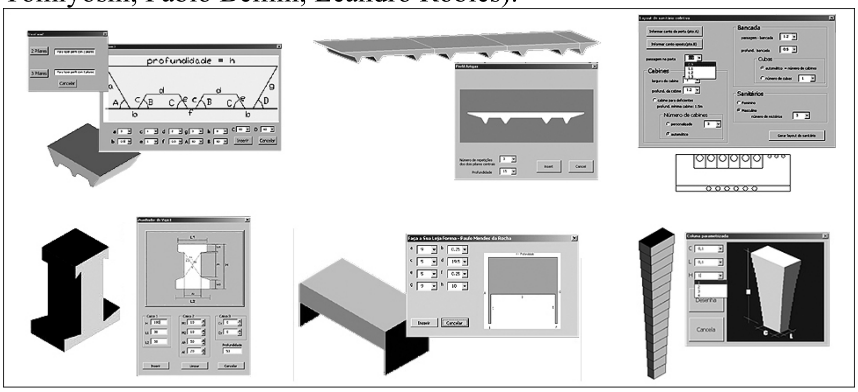

Figure 6: Some parameterization programs developed by students (top line, left to right – programs evolved from classroom exercises: Patrícia Falcão, Marina Otaviano, Marina Otaviano; bottom line, left to right – original programs by students: Min Lee, Marcelo Nakazaki, Wanessa Watrin).

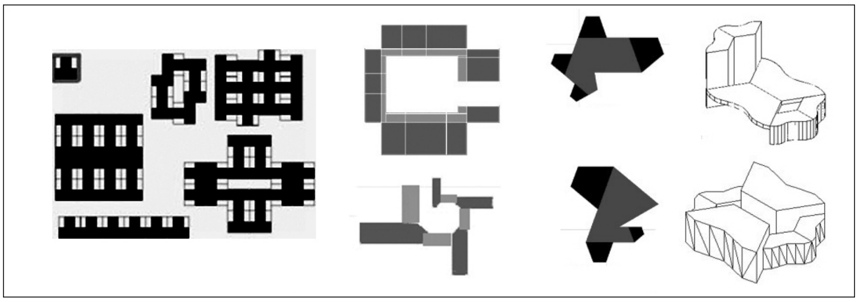

Figure 7: Architectural design exercises presented by FAU-USP students (top to bottom, left to right: symmetric housing, Daniela Costa; parametric school, Stella Tomiyoshi; recursive museum, Marcelo Nakazaki; recursive movie theater, Daniela Costa; parametric buildings, Daniela Costa).

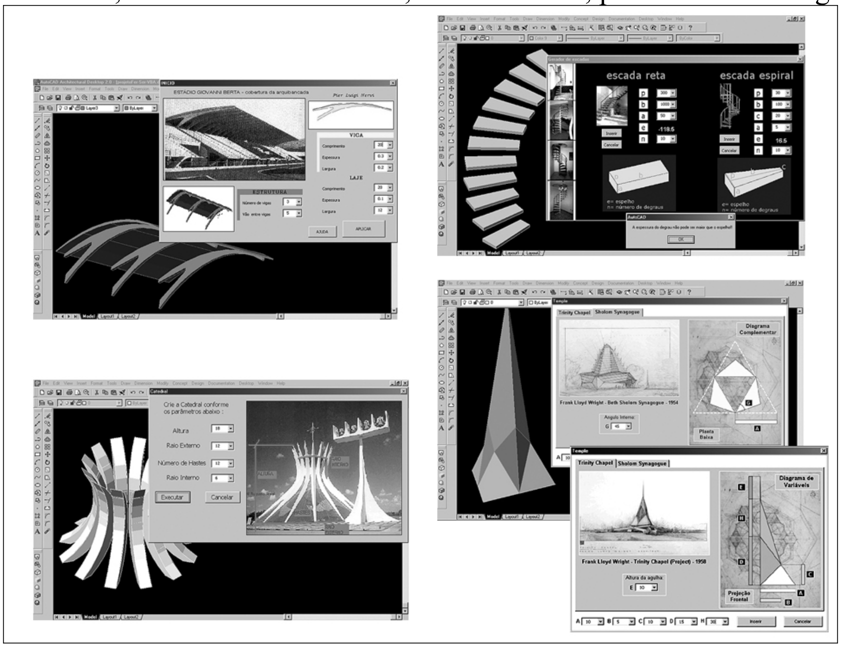

Figure 8: Some examples of final projects at FEC-UNICAMP (top to bottom, left to right: program for modeling parametric variations of a structure by Nervi, Fernando Basilio; program for modeling parametric variations of a Brasilia's cathedral, Patrícia Falcão; program for modeling stairs, Paula Baratella and Giovanna Bianchi; program for modeling parametric variations of a church and a synagogue by Wright, Daniel Moreira).

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Design from Known to New

-Issues of Generative Architecture under Digital Environment-

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Abstract

Given the power of digital design media, architects are confronting a new territory of architectural morphology. This paper attempts to explore the issues of generative architecture under digital environment. It is concerned with architectural precedents, their morphological attributes, and morphological analysis as the point of departure for generating new designs. Three design experiments are employed for the exploration. The first experiment addresses the issue of a single building. The second experiment focuses on the problem of urban architecture. The third design experiment places emphasis on the issue of urban landform.

In addition to the exciting novel forms and spaces generated from the afore-mentioned design experiments, a number of critical issues on generative architecture are raised and discussed in the paper. Among them are: (1) the concept and logic underlying the methodology of the design experiments; (2) the formulation of the generative design systems utilizing the existing morphological structures; (3) the employment of the digital design media (e.g. image processing, 3D abstraction and extrusion) for various purposes during the process of analysis and generation.

1. Background

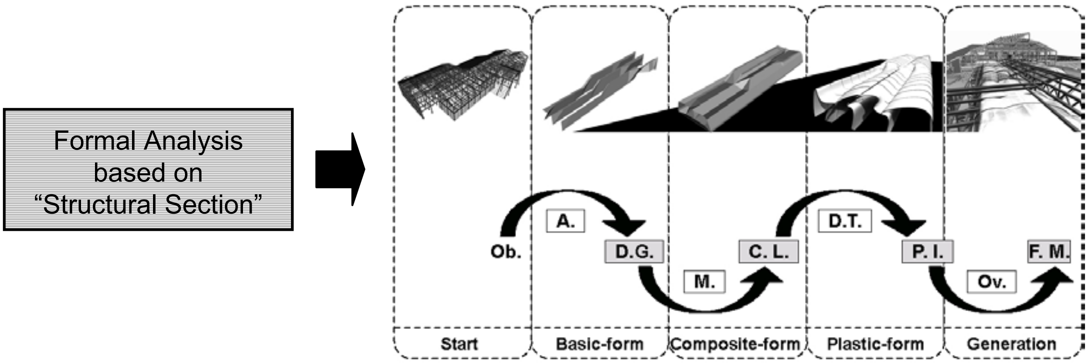
Given the power of digital design media, architects are confronting a new territory of architectural morphology. For example, the topological form generated by the mechanism of S-pline is widely accepted by some contemporary architects such as Greg Lynn. [1-2] Innovative architectural projects developed with powerful concepts under digital environment have also achieved acclaim in recent years such as FOA's Yokohama International Port Terminal. [3-5] It is thus arguable that crucial issues involved in the application of digital media in the process and/or the product of architectural design deserve a closer examination.

2. Three Design Experiments

This paper attempts to explore the issues of generative architecture under digital environment. It is concerned with architectural precedents, their morphological attributes, and morphological analysis as the point of departure for generating new designs. Three design experiments are employed for the exploration. The first experiment addresses the issue of a single building. The second experiment focuses on the problem of urban architecture. The third design experiment places emphasis on the issue of urban landform. They are shown as follows.

2.1 Experiment I: Design from Existing Structural Elements

The first experiment addresses the issue of a single building. The overall process of the experiment is shown in Figure 1. A method for analysing the formal structure of an existing building is developed on the basis of “structural section.” The process of generation consists of two steps: the derivation of basic form and the development of complex form. The major operation involved in the process is called “differential generation,” “Migration,” and “Constructive Linkage.” (Figure 3) The derived form is further explored through the operations of “differential transformation” and “plastic integration,” as well as “overlapping,” and “movement.” (Figure 4) For the generation of final plastic form, four types of structural and spatial overlaps are identified. (Figure 2)



Ob.: Object; A.: Analysis; D.G.: Differential Generation; M.: Migration; C.L.: Constructive Linkage
D.T.: Differential Transformation; P.I.: Plastic Integration; Ov.: Overlap; F.M.: Flexible Movement

Figure 1. Overall Process of the Formal Operation

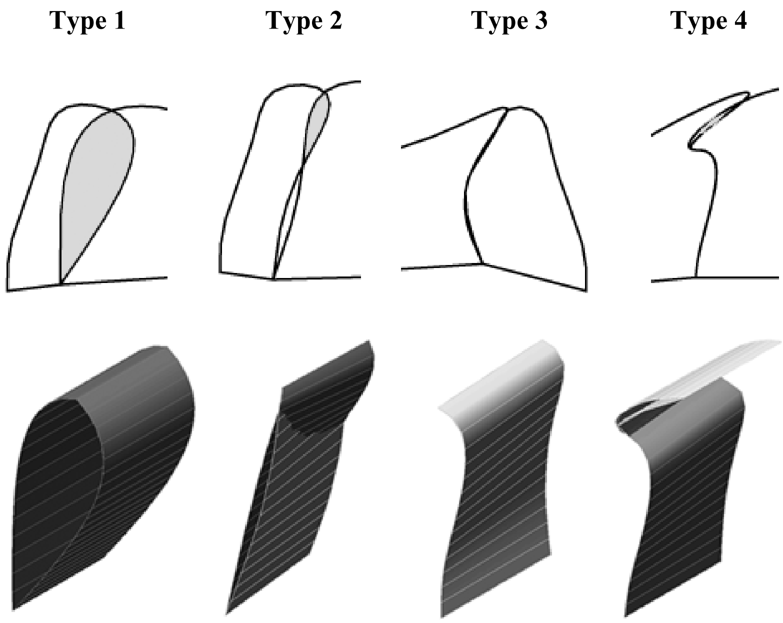


Figure 2. Types of Structural and Spatial Overlaps in Generation

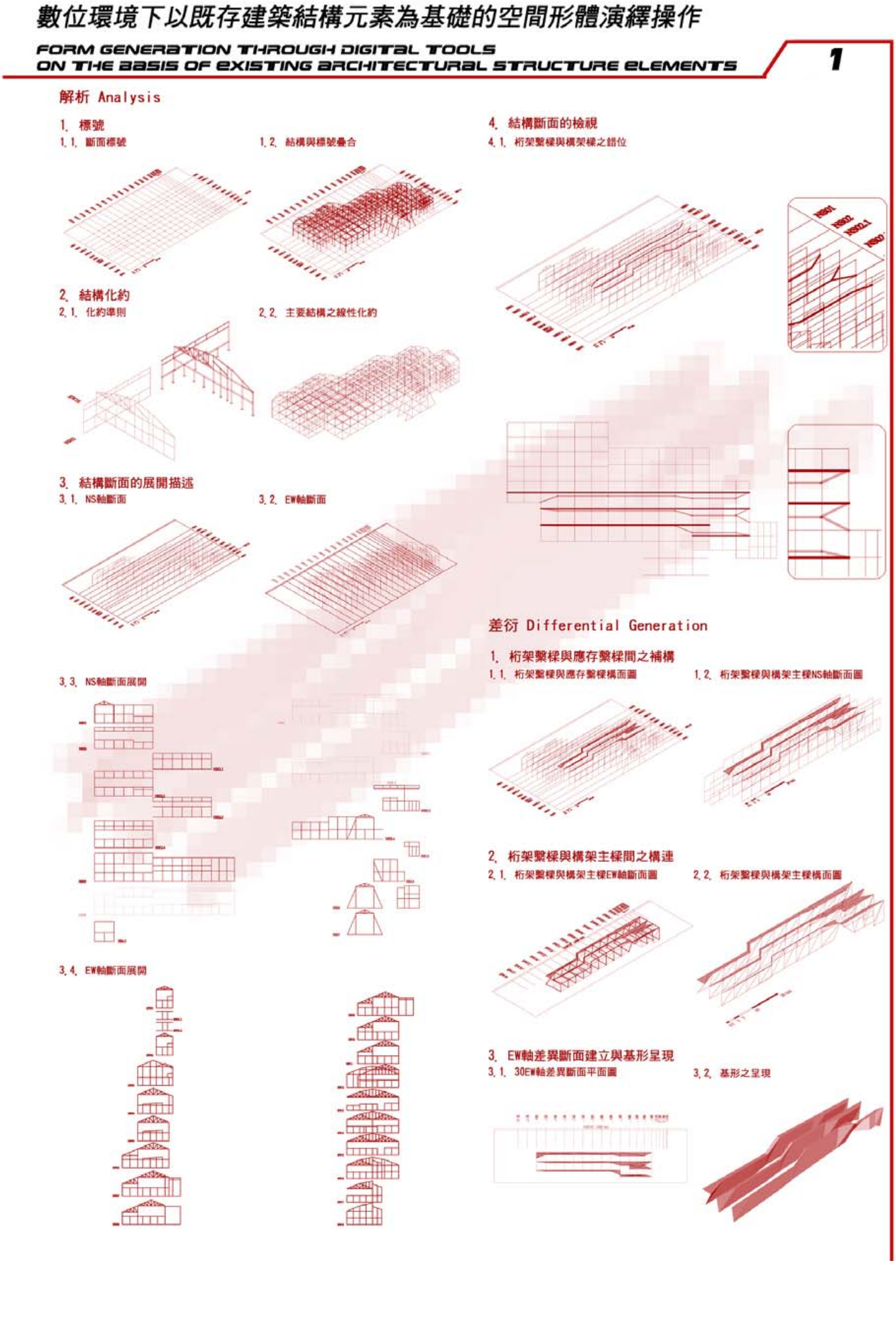


Figure 3. Analysis and Differential Generation

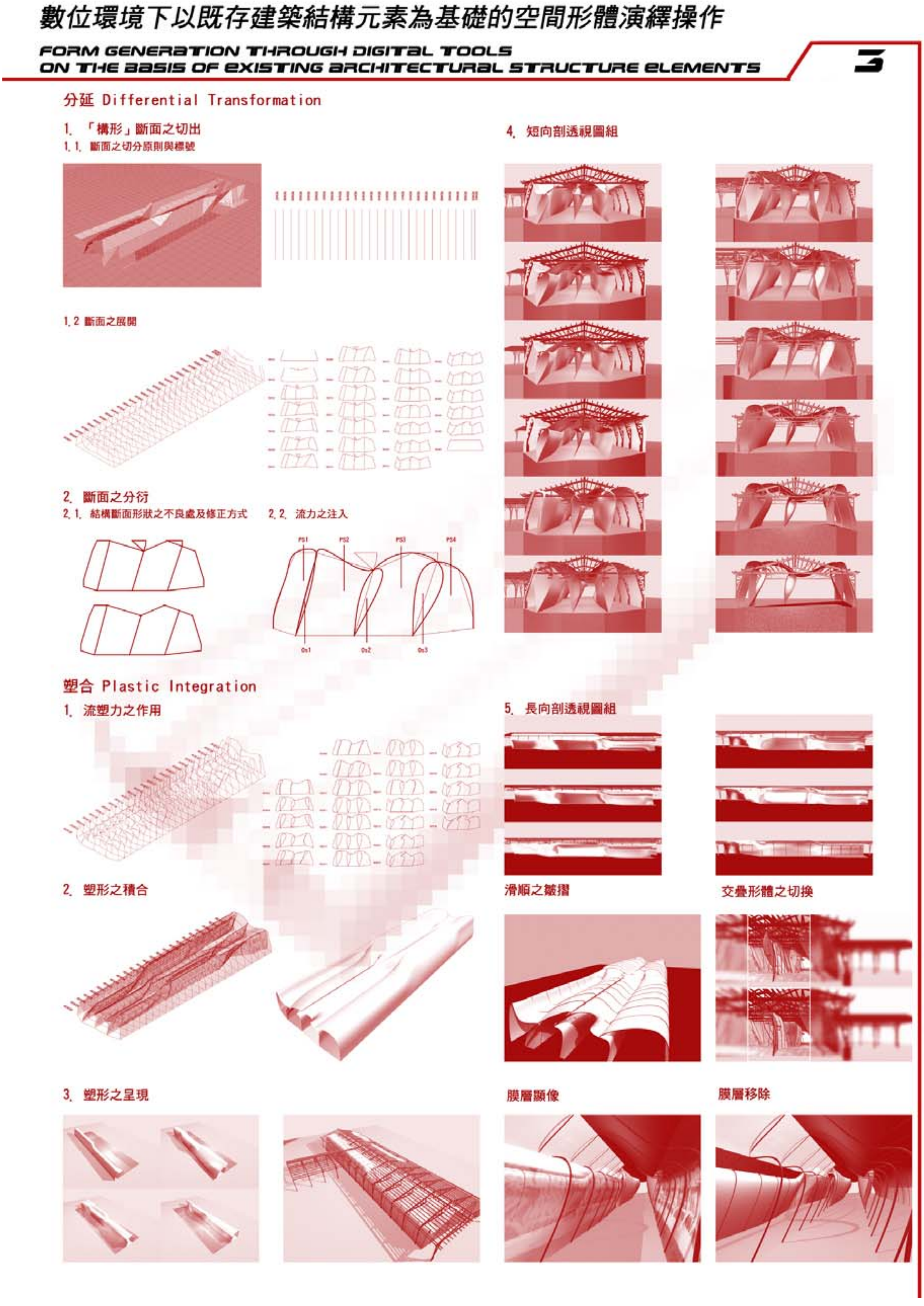


Figure 4. Differential Transformation and Plastic Integration

2.2 Experiment II: Design Based on Image-Space Methodology

The second experiment focuses on the problem of urban architecture. The spatial elements, which constitute the "skins" of the streets and the buildings of the city blocks, are investigated. The images of the past and the present "skins" are collected, compared and analyzed. An image-space methodology is developed to deal with the generation of the urban "skins" from 2D images to 3D spaces. It can be applied to address the problems of "deep," "shallow," and "planar" skins, respectively. Underlying the methodology is the notion of "Infra-Surface," which is based on the philosophical theories of Deleuze and Duchamp. As shown in Figure 5, the procedure of the experiment is divided into three parts; each part consists of two stages, and each stage has a number of steps.

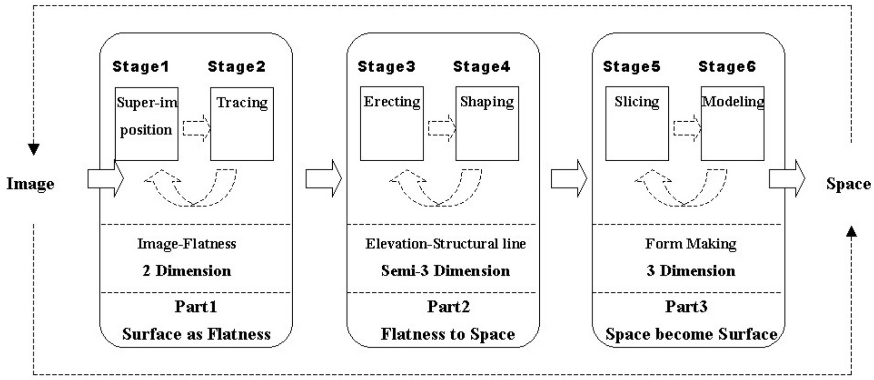


Figure 5. Procedure of Image-Space Methodology

Part 1 Surface as Flatness (2D)
Stage 1 Superimposing Images: to collect, select, and superimpose the images of the past and the present images to derive a precisely positioned, overlapped image.
Stage 2 Tracing Structural Lines: to trace the crucial contour lines of the overlapped skins in the image. The vanishing point and the new spatial relations are established

Part 2 Flatness to Space (between 2D and 3D)
Stage 3 Erecting Perspective Structure: to erect the spatial structure from perspective. The space produces certain semi-space effect.
Stage 4 Shaping Initial Form: to derive and edit the initial form through the definition of "infra-surface."

Part 3 Space to Surface (3D)
Stage 5 Slicing Initial Form: to simplify the complex wire frame and erase the redundant lines to derive a set of sectional slices for forming a new frame structure.
Stage 6 Modelling space: to complete the envelope for the structure and to add thickness for the structural surface.

Three building sites in Taichung City, Taiwan are selected to test the applicability of the procedure. They represent three different problems of "skin" design in urban architecture: deep, shallow, and planar. Some reasonable architectural programs are assumed for the experiment, such as exhibition, theatre, gallery, and commercial shops. The designs for the three sites are shown in Figure 6.

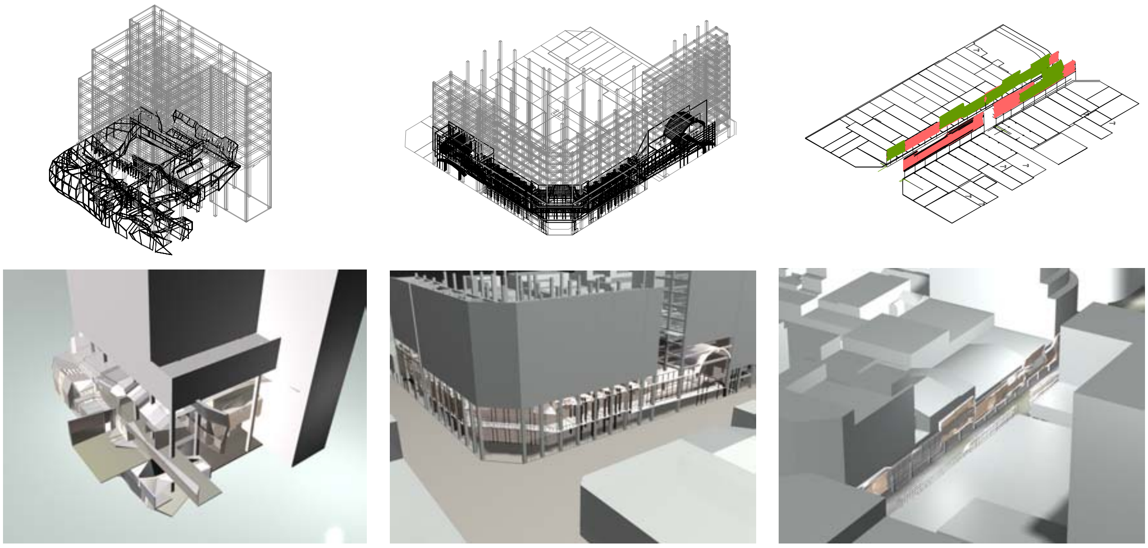


Figure 6. Derived Designs with Deep (Left), Shallow (Middle), and Planar (Right) skins

2.3 Experiment III: Design through Wire-Frame and Graphic Analysis

The third design experiment places emphasis on the issue of urban landform. Three classes of urban landform are identified: district, city block, and building. They are made up of city blocks, buildings, and structural elements, respectively. Wire-frame and graphic analysis are employed for analysis and generation. Specifically, a computer-based framework for the generative meshes at the three levels of hierarchy is established. The framework consists of four operations: "clustering," "tracing," "blurring," and "weaving." Figure 6 illustrates the process of transforming urban grid/mesh to wire-frame diagram and land surface.

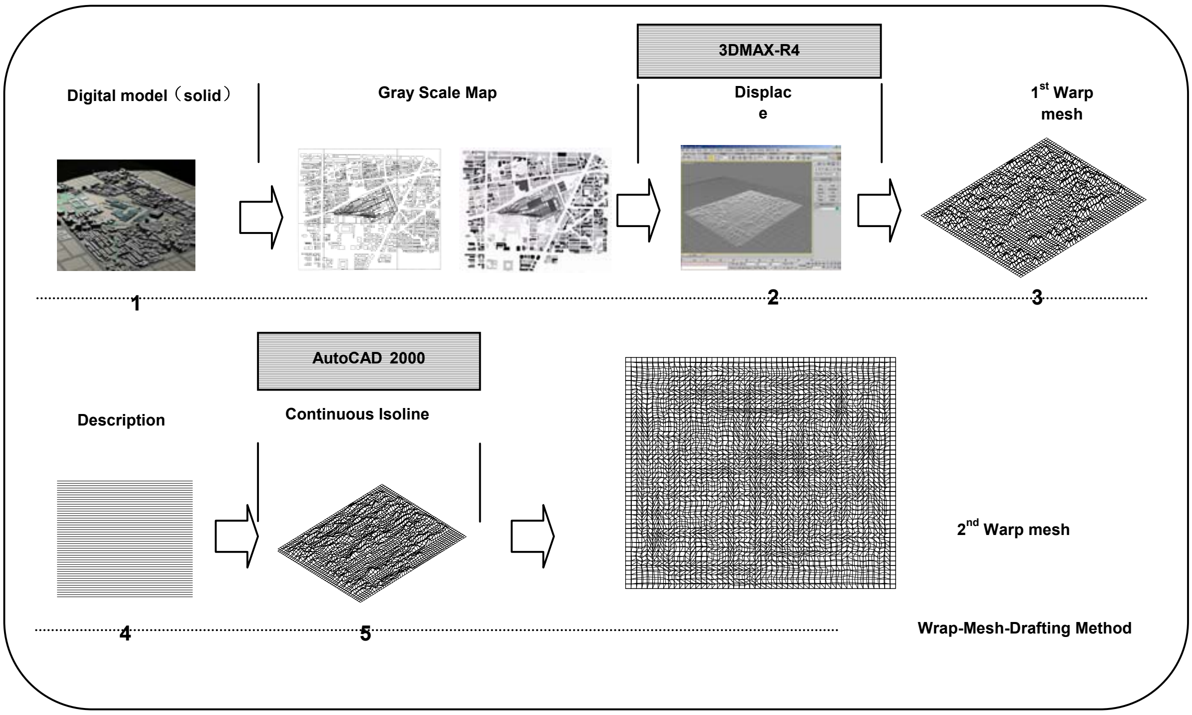


Figure 7. Wire-Frame Analysis and Generation

On the basis of the wire-frame analysis for the urban landform, a building design experiment is conducted. It consists of two parts. The first part deals with an existing building, in which the derived urban mesh intervenes for finding corresponding relations with the building. The intervention provides an opportunity for developing a new form that may arguably create certain spatial relations with the existing formal condition. The second part of the design experiment defines the "land surface" as the interface for architectural form. It uses the wire-frame as a fundamental form for development. It is followed by a series of formal operations between wire mesh, existing building, and the urban landform and thus establishing a new spatial relation among them. (Figure 8)

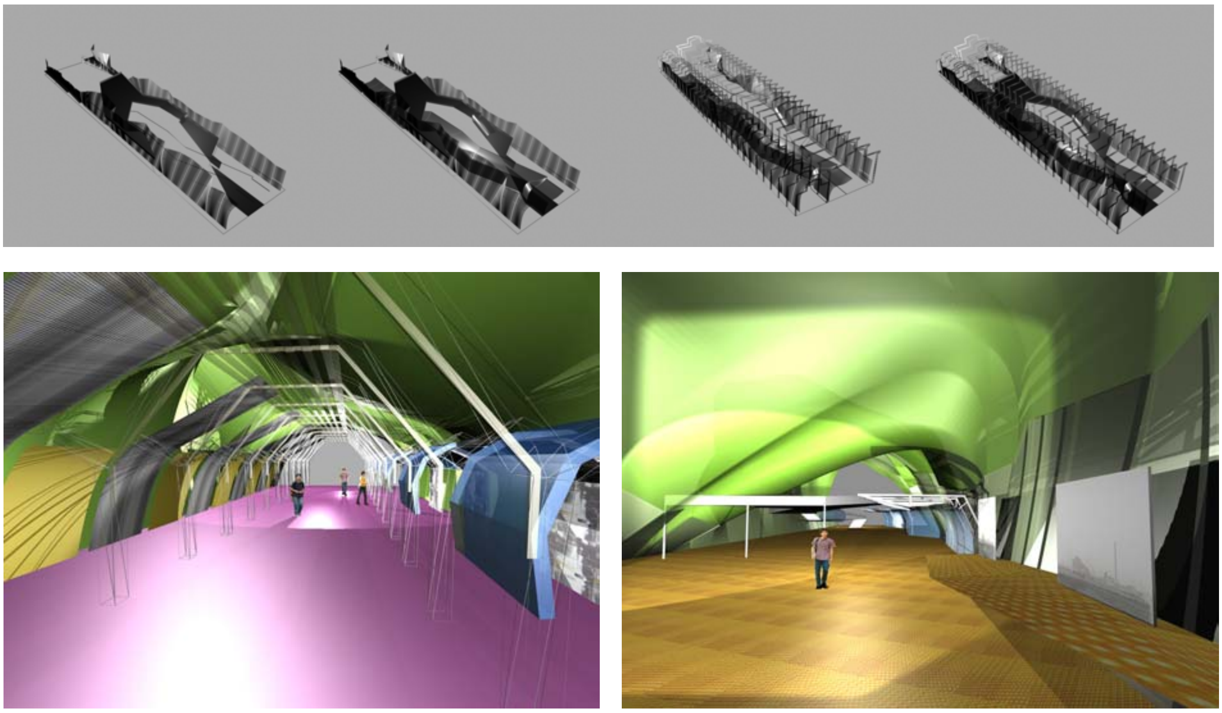


Figure 8. Process of Formal Operations and Two Interior Views

3. Discussion

In the afore-mentioned three design experiments, many exciting novel forms and spaces are generated. Specifically, the first experiment deals with design from existing structural elements. After a detailed analysis based on structural section, a procedure is developed for the generation of plastic form, which is different from the typical “topological form” and may be termed as “wavy form." The second experiment generates design based on image-space methodology. The images of the past and the present “skins” are incorporated to generate the three types of urban surfaces. The final forms exhibit the potential of the “infra-surface” that constitutes the skins of urban streets and buildings. The third experiment generates design through wire-frame and graphic analysis. Emphasis is placed on the spatial relations between the existing building and its surrounding urban landform. It is notable that many hidden, critical spaces can be identified and transformed into concrete curving spaces by the assistance of wire-frame.

In addition, a number of critical issues on generative architecture are explored in the three design experiments. They are (1) the concept and logic underlying the methodology of design generation; (2) the formulation of the generative design systems utilizing the existing morphological structures, ranging from the individual architectural elements to the integral urban forms; (3) the employment of the digital design media (e.g. image processing, 3D abstraction and extrusion) for various purposes during the process of analysis and generation. As exemplified in the first design experiments, “differential generation” and “differential transformation” constitute the key concept for the methodology. In the second experiment, the notion of “infra-surface” is posed. In the third experiment, architectural design is seen as an integral whole which has to do with three levels of urban landforms. Following that, a systematic procedure has to be developed. In the three experiments, existing morphological structures are employed as the point of departure. Thus, it is necessary to establish a strategy for analysing the existing structures and a mechanism for generating new designs. Finally, the digital design media are powerful in form generation and real-time operation. Nevertheless, it is suggested that the media be guided by thoughtful design concept and procedure. The latter two, in the case of this study, come from the deep understanding about and creative deduction from the existing morphological structures.

Acknowledgement

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HUMAN-ARTIFICIAL ECOSYSTEMS:

SEARCHING FOR A LANGUAGE

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1. INTRODUCTION

The most recent advances of artificial life scientific research are opening up a new frontier: the creation of simulated life environments populated by *autonomous agents*. In these environments artificial beings can interact, reproduce and evolve [4, 6, 15], and can be seen as laboratories to explore the emergence of social behaviors like competition, cooperation, relationships and communication [3, 5, 7] . It is still not possible to approach a reasonable simulation of the incredible complexity of human or animal societies, but these environments can be used as a scientific or artistic tools to explore some basic aspects of the evolution [1, 2, 3, 9, 11, 12, 13, 14, 15, 16].

The combination of these concepts with robotics technology or with immersive-interactive 3D environments (virtual reality) are changing quickly well known paradigms like *digital life*, *man-machine interface*, *virtual world*. The virtual world metaphor becomes interesting when the artificial beings can develop some form of learning, increasing their performances, adaptation, and developing the ability to exchange information with *human visitors*. In this sense, the evolution enhances the creative power and meaningful of these environments, and human visitors experience the emotion of a shift from *a simplified simulation of the reality* to a *real immersion into an imaginary life*. We may think that these realization are the first *sparks* of a new form of life: simulated for the *soft-alife* thinkers, real for the *hard-alife* thinkers, or a simple imaginary vision for the artists.

The key aspect of artificial societies is the potential to develop an internal knowledge in the community. This knowledge can be expressed through the ability to modify their behavior and relationships creating structures and complexity in the society. In this paper we refer to several experiments where a community of artificial individuals, equipped with a personal neural network, autonomously develop a common set of symbol-meaning associations. Furthermore we illustrate the state of the art of development of the *E-Sparks* project. Goal of the project is the realization of a symbolic interactive installation where artificial beings can communicate with the humans. In this installation the creature progressively develop the ability to learn and classify the words pronounced by the humans and diffuse in the community up to the emergence of a common and autonomous vocabulary.

2. THE SOCIAL LEARNING AND THE PARTIAL EMULATION MODEL

In our approach, the basic concept is to create a continuous learning mechanisms to achieve complex task in social context. The aspect of social learning is crucial to organize the individual learning and give to the society the ability to grow in a rich cultural progression. The social way to the development of knowledge and intelligence is much more powerful and it requires the definition of a mechanism to exchange information between the individuals.

2.1 The partial emulation model

In [3] we have introduced a simple and basic model in order to organize the individual learning in the social context: the *partial emulation model*. In this approach the behaviour and its success degree is viewed as a knowledge level reached by the individuals.

In order to go in little detail of the model we define better the problem. Let suppose a society of artificial individuals (*autonomous agents*). Each individual continuously try to increase the degree of success of own behaviour trough a own path of trails, successes and flops (*individual learning*). Now let suppose that two individuals have a meeting. Each one of the two individuals have a specific behavioural configuration. The problem is: which is a good model in order to take advantage by the interaction in terms of exchange of information or evolve the behaviour of the interacting individuals.

The most simple model we can imagine could be synthesized by the following sentence:

- *if you are more successful than me I adopt your behaviour* -.

Unfortunately this model has two very important lacks:

1. In most of the cases is very difficult decide if the other is *better than me*. In general this is a result through a series life cycles and meetings.
2. None new behaviour is produced in the society by the way of the interaction.

Using this model, in some case, the final result of the social learning could be worst than the best individual learning.

The partial emulation model is a slight extension of this model. It could be synthesised by the following sentence:

- *it is generally convenient for me, try to partially emulate your behaviour –*

We tested very good results of this model in learning problems (food tracking in [3]). A complete theoretical justification of this model is not simple. It important take into consideration several aspects:

- A general trend to clusterize the behaviours around the most successful behavioural centroids.
- A dynamic equilibrium between the *individual learning* which promote new behaviours and the emulation which promote the concentration of the resources around few evolution lines.

In terms of the degree of success, this model produces results which are much better than a similar society with none interaction models.

A basic explanation is that the *adaptation* is a mechanism which promote the synchrony between the following two events:

- the *existence* of a specific behaviour
- a *high success degree* associated to that behaviour.

This means that we have a high probability that the modified behaviour after the partial emulation is better than the original behaviour. In this sense the partial emulation model is a synchronic model promoted by the adaptation.

By a mathematical point of view the partial emulation model can be applied in different way depending by the contest.

In [3] we applied this model in order to develop in a society the ability to understand that the tracking of food bits is a good strategy to survive. In that case each individual was equipped with a neural network controlling the movement. The input of the networks were the previous movement status and the signals from sensors for substances in the neighborhoods of the individuals. The *behaviour* is represented by the weights of the neural network.

When two individuals had a meeting they modify their weights by a factor ? :

$$W_{Ai} = W_{Bi} * ? + W_{Ai} * (1-?)$$

Where W_{Ai} is the i-th weight of the network of the first individual and W_{Bi} is the i-th weight of the network of the other individual; ? is the emulation factor.

An interesting aspect of the social learning is the feature of dynamics and *volatility* of the knowledge. The produced knowledge is a product of the whole society but it is moved dynamically between the various individuals. Although the knowledge is generated during the life of the individual, it can be transmitted through the generations.

2.2 The development of an autonomous language

The next experiment we have set up is the development of an autonomous primitive language in the artificial society as a self-organising process of symbol-meaning relations shared by the community. Our intention is not to modelling the language of real animal or human communities, but we refer to a completely imaginary artificial society. These societies could be regulated by mechanisms much simpler and probably different from the biological ones. Furthermore, with the term *primitive language* we refer to the sharing process in the community of a symbol-meaning dictionary. In principle the term *symbol* is general and it can assumes different meaning depending by the context (a gesture, a body expression, a phoneme, a sound, a sign).

The development of an autonomous language is a very complex task. In order to achieve concrete results we have to distinguish several stages of development. In the following scheme we try to divide the problem in two different stages of development. These stages describe only one of several possible ways for the formation of a shared dictionary.

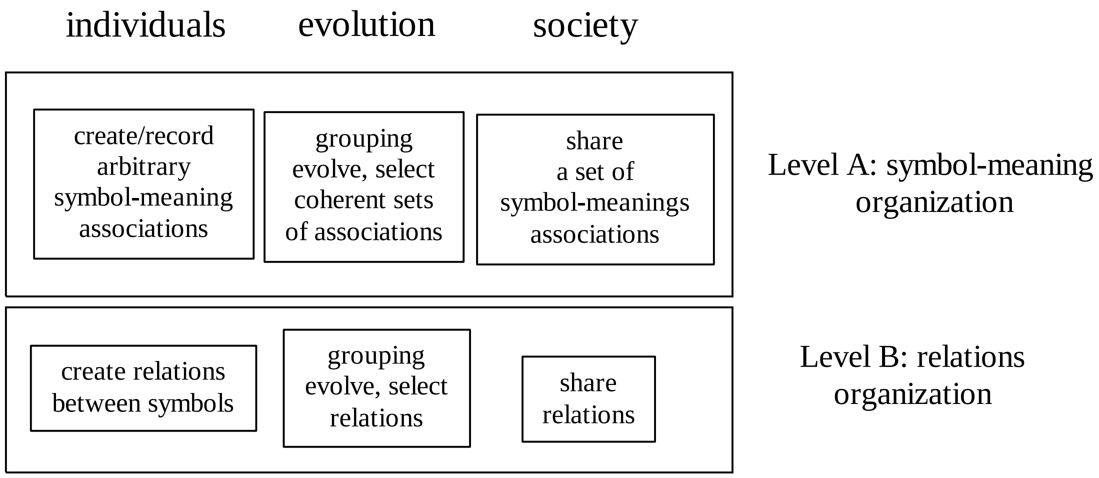

Fig. 1: Processes for the development of an autonomous language in artificial societies

In the left column of scheme of fig. 1 we represent the processes operating at the individual level, in the central column the processes involved during the evolution through the social communication and in the right column that ones operating at society level. The processes involved in the level A consists in the autonomous creation of a basic set of symbol-meaning associations shared by the community. In this process the symbols are progressively created by the individuals; grouped, evolved and selected through the social communication. At the society level a set of shared symbols-meaning association progressively emerges.

The processes involved in the level B are referred to the emergence of relations between symbols at individual and society levels. This level could be seen as the beginning of symbol composition in order to pass to a higher level of language development.

At the current level of the research reflected in this paper, we take into consideration only the processes involved in the level A. We have realized two experiments to explore these processes. The first experiment consists in a study of the symbol-meaning organization in the society using the partial emulation model. The second experiment is a prototype for human-artificial exchange for an interactive installation where the artificial creatures can assume words from speaking human visitors and activate the sharing process in the community.

Both the experiments are based on the same model for the artificial world. This model is described in the following paragraph.

3. THE EMERGENCE OF A SHARED SET OF SYMBOLS IN THE COMMUNITY

The artificial life (*alife*) environment is a three-dimensional space where the artificial individuals (or *autonomous agents*) can move around. During the single iteration (*life cycle*) the individuals move in the space interacting with other individuals exchanging information. A population of 512 individuals has been considered.

The individual is composed by the *genotype* and the *artificial brain*. The *genotype* is composed by parameters which does not change during the individual life, like dynamics and interaction parameters. The brain includes the current values of the information coded in the weights of an artificial neural network controlling the communication and a memory zone where the known symbols are recorded. The memory is divided in cells. Any cell represent a meaning and the content of the cell represents the symbol currently associated to that meaning. For simplicity, the symbols are treated as *words* described by two normalised parameters (x and y) and the memory is fixed on only 4 words. Therefore any cell of the memory contains two floating numbers between 0 and 1. A scheme of the neural network and the memory archive is reported in fig. 2.

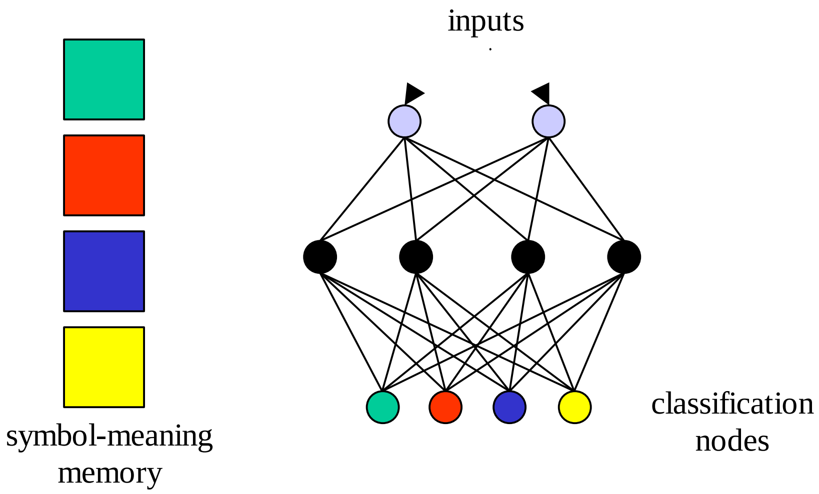

Fig 2: The network for symbol classification into meanings

The network has the goal to classify the input words in one of the four meanings. This is obtained considering the result of the classification as the highest value of the output nodes. The individual continuously try to classify their own words using the network. In some case the result is correct, in other case the result is wrong. A global efficiency is computed. The errors are due to two possible reasons:

1. the neural network is not still well trained to classify all the words
2. the own set of symbols are ambiguous. This means there are too similar symbols for different meanings.

In case 1, the efficiency can improve during the learning phase. In case 2, the efficiency could remain very low. In this sense the efficiency of the network is a measure of the level of learning of the individual but also of the ability of the individual to develop a coherent and clear set of symbols. The individuals continuously try to modify the network weights in order to achieve a better performance (*self-training mechanism*). This kind of self-learning is individual.

When a meeting between an individual A and another individual B occurs, a communication event is generated. Each one of the two individuals chooses randomically a cell of own memory and communicates to the other individual the word contained in that cell and related meaning.
In the meeting, the partial emulation model is applied in two directions:

?? partial emulation of the weights of the neural network
?? partial emulation of the own word corresponding to the same meaning of the input word.

The emulation factor is very low (5 %). The emulation is applied only to the individual at low network efficiency and only if the difference between own word and the input word is below a specific threshold.

This model represents a premium to the individuals which are able to develop a good classification system and a good symbol set. It is fundamental to outline that the premium is intended for the set of symbols and not for the single symbol. In some sense this model is an implementation of the criteria of the *survival of the clearest* enunciated by Pinker in the evolutionary theory of the language [10].

The results are illustrated in the plot and the images of fig. 3. These images represent the two coordinates that describe the word (*x* and *y*). The colour of the symbol represents the meaning. At the beginning (time=cycle 300), both words and meaning are very scattered. During the evolution some clusters emerge (time=cycle 8000).

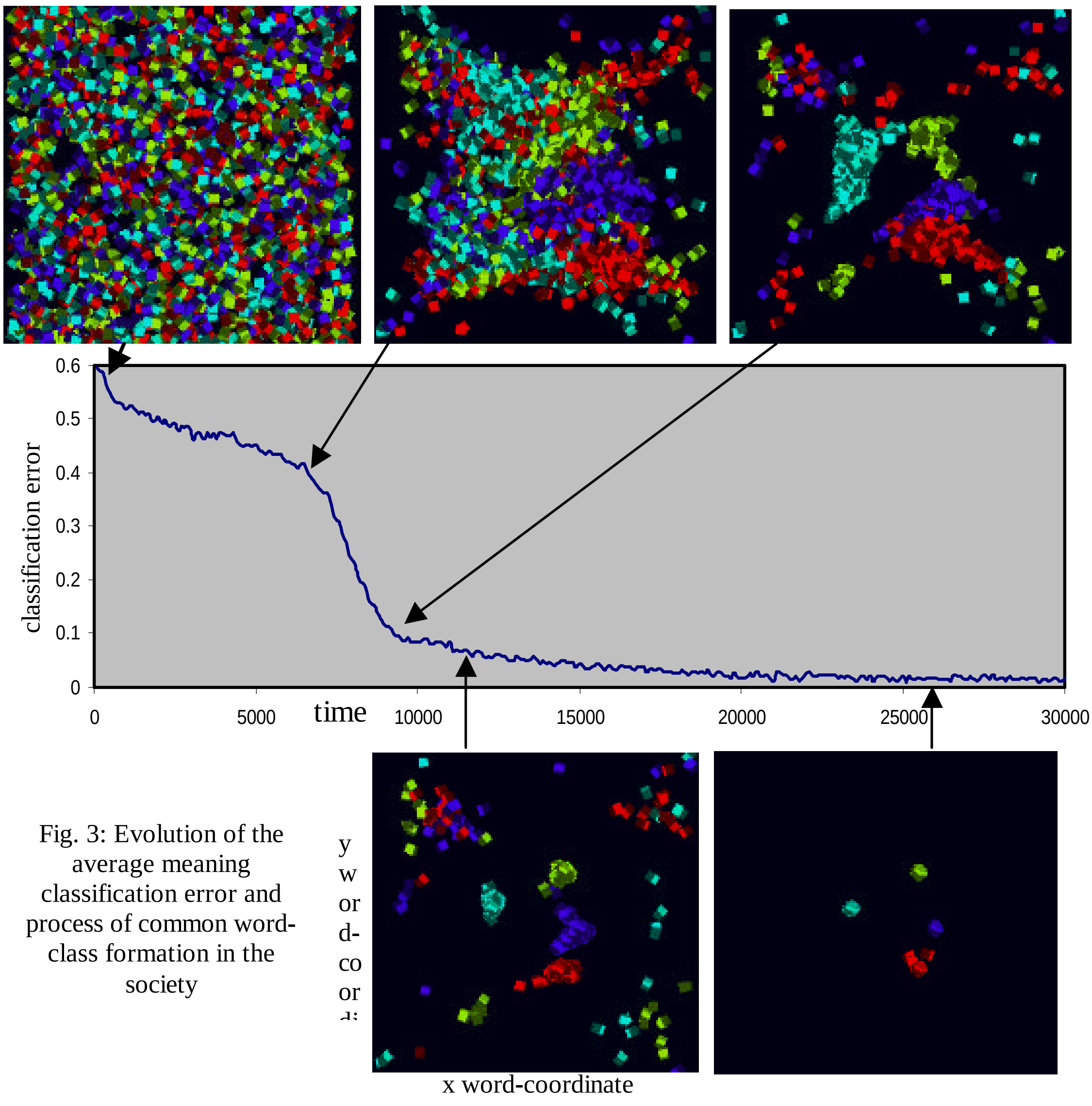

Fig. 3: Evolution of the average meaning classification error and process of common word-class formation in the society

These clusters are due to group of individuals which use a similar word to identify a similar meaning. This effect if pushed up by the formation of groups of individuals in the physical space. These micro-societies create niches of evolution and the communication level is very high. In fig. 4 an example of grouping in the physical space is illustrated.

This effect produces the creation of local dialects (see image corresponding to the cycle 11000 of fig. 3). The dialects tend to disappear when the communication between different groups occur.

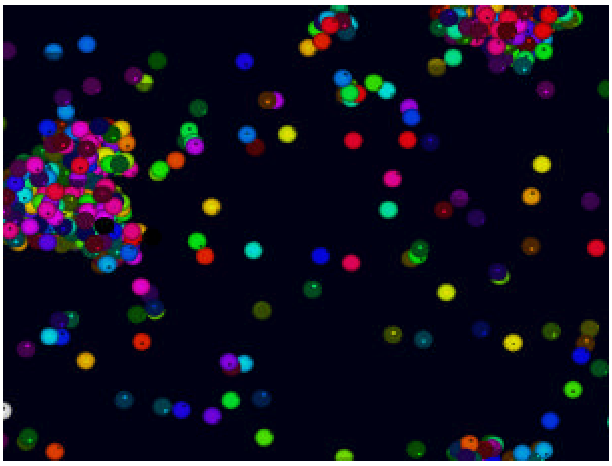

Fig. 4: formation of individual groups in the physical space

Through the partial emulation mechanism, the individuals involved in these group tend to share the same set of symbol-meaning associations. The convergence on a specific set is driven by that individuals who are more able to develop a set with good differences between the symbols and good ability to correctly classify the symbols with own neural network.

Is very interesting to note the strong increase in the average classification ability of the individuals when the first clustering structures occur (see fig. 3). Under clustering condition the neural networks become less confused by the noise introduced by the scattering; the partial emulation starts to help the individual learning and the classification starts to work. At the end, when a common well defined 4-clusters set is established, the classification problem becomes more simple and the classification error reaches the minimum values.

The error is computed as the fraction of wrong classifications of own words. A 1.0 value means a wrong classification for all the words in the memory cells. A 0.0 value means a completely correct classification. The value reported in the plot of fig. 3 is averaged over the whole population. At the end of the evolution, the average classification error is 0.03. This means that about only 12 individuals over 100 do wrong in the classification of one word over four.

4. SPEAKING WITH HUMANS IN THE HYBRID ECOSYSTEM

In the previous sections we have shown the realization of an artificial world where the creatures can learn and exchange information in order to create the base for an autonomous language. So far all the world is confined in the digital domain. A real jump in the potential of these world is to establish a contact between this world and humans. The idea is not the human control of the world, but a sort of cross-fertilisation of elementary words. Following this direction, the digital communities developed along these experiments have been connected to an interactive installation where communication with humans is possible. This is an immersive environment where humans and artificial individuals can exchange sound messages.

The first step has been the creation of the interaction mechanism. The artificial individuals, appear as solid shapes in a 3D virtual environment projected over a 2D screen. The area for the human interaction consists in the area in front of the screen. In such a way we have extended a dimension of the environment in the real world building an hybrid real-digital ecosystem. The interaction area is observed by a video-camera acquired in the computer. A tracking program detects the people presence in terms of change detection in the image. This information is mapped as substances admitted by the real people in the digital environment. The metaphor is that a person releases substances when moves in the hybrid environment. The creatures attracted by these substances come towards the people and the communication starts (see fig. 5).

Fig. 5: Interaction human-artificial in the hybrid environment. On the left, playing with creatures in the "E-Sparks" first installation prototype. On the right, the alife-dance performance "Aurora di Venere" (Theatre of Palais of San Vincent, Italy). The dancers play with the digital creatures projected over a semi-transparent screen of the theatre's stand.

The second step regarding the speaking communication is still in progress. This step can be divided in two problems: a) the word speaking-receiving facility for human-creature exchange and b) the connection between the social context discussed in the previous paragraph and the interactive installation. In this paper we refer to first of the two problems.

In order to allow the communication, we installed spatial microphones in the installation. The voice signal is sent to the creature approached for communication. When a visitor speak in the environment, the creature apply a series of reactions as illustrated in the scheme of fig. 6.

1. Wait for voice signal. When the energy of signal go over a minimum threshold the word capturing reaction is activated.
2. When the energy of the signal go under a minimum threshold the capturing reaction is deactivated and a word is insulated form the context and supplied to the analysis chain.
3. The word is converted in parameters. These parameters describe the sequence of 20 milliseconds blocks of the raw signal. Each block is described by 14 parameters computed trough an auto-regressive algorithm. Typically, a whole word is described by 500-1000 parameters depending by the duration in time.
4. The input word is classified in one of the words currently present in the memory cells (vocabulary). At the current state of art, the euclidean distance from any word is computed and the word corresponding to the minimum distance is selected. In next step the neural network will be introduced in substitution of the deterministic rule. The criteria of the continuous self-learning over the words in own vocabulary is going to be used (as that one illustrated in the previous paragraph).

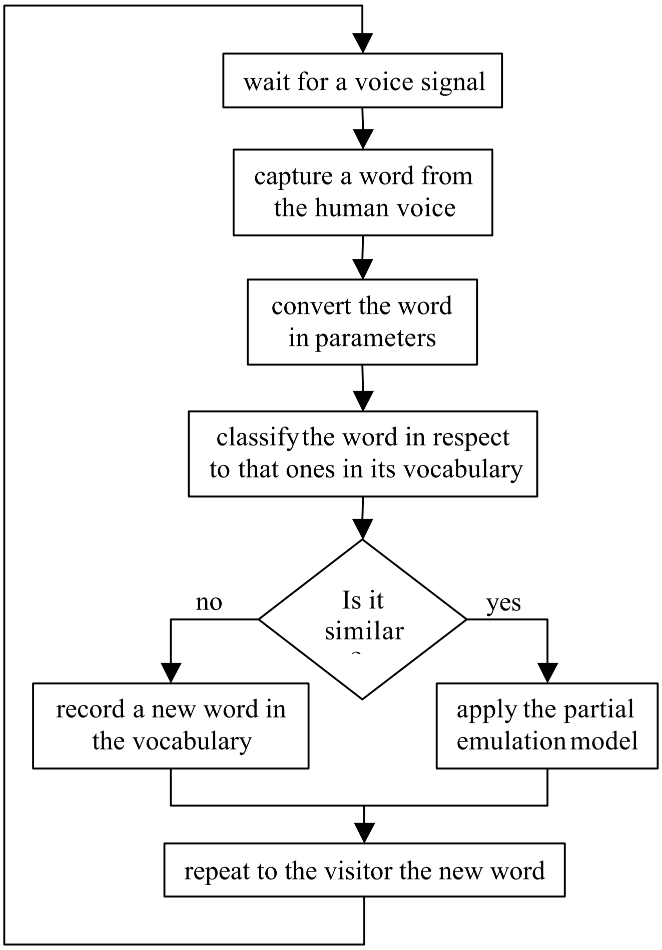

Fig. 6: the creature interaction with the visitor

5. If the minimum distance is under a specific threshold, the corresponding word is recognised as *similar* to one *known* word. In this case, the partial emulation model is applied: any parameter of the recognised word is lightly moved towards the corresponding parameter of the input word following a very low emulation factor (typically 0.05).
6. Otherwise, if the minimum distance is over the threshold, the input word is recognised as a *new word* and recorded in the vocabulary if it is not full already.
7. The emulated word or the new word is synthesized in a new raw signal that is sent to the speakers.
8. Finally the creature is waiting for a new voice signal.
9. After a while the connection is deactivated and the creature is free to go around and applying exactly the same procedure when another creature is met.

In this way, the words admitted from the visitor are diffused in the society during the next communication phase. In the diffusion, the words are distorted in relation to the words already known by the creatures. If the visitor repeat several time the same word, he pushes the creatures toward an exact learning of that word. Otherwise, he can wait and to observe the influence of own interaction on the creature language.

In order to point out the "speaking procedure" a one-to-one experiment has been prepared. In the experiment, a person speaks directly with a creature (see fig. 7).

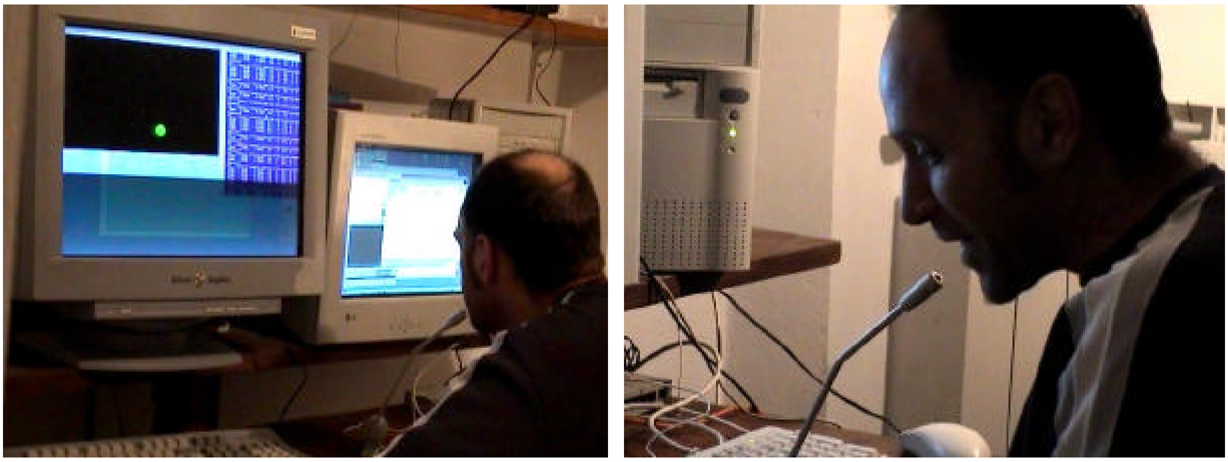

Fig 7: Piero speaking with a simple sphericalcreature

The result is very interesting. For the first learning phase the creature repeats almost the word pronounced by the human speaker. When its vocabulary is quite full, the reaction of the creature is quite surprising, especially when the speaker repeat several time the same new word. Firstly a strange answer is given and than the creature try to progressively distort a known word towards the word repeated by the speaker.

This exercise allow to the speaker the possibility to drive a game with ambiguities and projection of meanings in such a way that the creature seems much more smart that really it is. It exactly this transfer of the visitor in the metaphor of the *real digital life* that we are interested to realize in the *E-Sparks* project: create a theatrical representation of an imaginary life founded on the same evolutionary mechanisms that are at the base of our evolution.

CONCLUSIONS

Rather than conclusions, this experience opens many questions like:
what does digital life will mean in our next future ?
is it really possible to develop an autonomous culture in artificial worlds ?
how far this knowledge could go ?
is it possible to found the base of the language formation on an evolutionary context ?
could be it possible interpret psyche, affect, consciousness on the same evolutionary base ?

Maybe the only reasonable conclusion today is to raise these questions. Using imagination and art to hypothesize some answers.

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Narrative Spaces:
bridging architecture and entertainment via interactive technology

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Abstract

Our society's modalities of communication are rapidly changing. Large panel displays and screens are being installed in many public spaces, ranging from open plazas, to shopping malls, to private houses, to theater stages, classrooms, and museums. In parallel, wearable computers are transforming our technological landscape by reshaping the heavy, bulky desktop computer into a lightweight, portable device that is accessible to people at any time. Computation and sensing are moving from computers and devices into the environment itself. The space around us is instrumented with sensors and displays, and it tends to reflect a diffused need to combine together the information space with our physical space. This combination of large public and miniature personal digital displays together with distributed computing and sensing intelligence offers unprecedented opportunities to merge the virtual and the real, the information landscape of the Internet with the urban landscape of the city, to transform digital animated media in storytellers, in public installations and through personal wearable technology. This paper describes technological platforms built at the MIT Media Lab, through 1994-2002, that contribute to defining new trends in architecture that merge virtual and real spaces, and are reshaping the way we live and experience the museum, the house, the theater, and the modern city.

1. A new architecture for the information society

Architecture is no longer simply the play of masses in light. It now embraces the play of digital information in space.
William J. Mitchell, Dean of MIT's School of Architecture and Planning, in: e-topia, pg. 41

Our daily lives are characterized by our constant access -to and processing -of a large quantity and variety of information. In the last decade, the rapid diffusion of the information superhighways, the amazing progress in performance and processing power of today's computers, paralleled by a drop of their cost, has determined a profound transformation of western world societies. In addition to being transmitted by the traditional media, such as television, radio, the newspaper, the book, the telephone, the mail, information is conveyed to us in electronic form by the home or office computer, public billboards, private hand-held PDAs, cellular phones, and soon even by our wrist-worn watch and clothes. The potential offered by the rapid and efficient exchange of data, globally, between individuals and organizations, delineates new social, economic, and cultural models based on the exchange of knowledge. The information society is defined by the primary role of information, such that power and growth are associated to our ability to receive, store, process, and transmit information instantaneously.

Screens are everywhere, from the large billboards commonly embedded in the contemporary urban city-scape, to the video walls which welcome us in the entry-hall of corporate headquarter buildings, the desktop computer monitor in our home, the PDA in our pocket, or the tiny private-eye screens of wearable computers [1] [figures 1 and 2].

Figure 1. Aerial view of the Shibuya district in Tokyo showing of a large variety of LCD displays and animated screens distributed in the city-scape

Figure 2. Fashionable wearable display projecting an image on the viewer's eye through the private-eye

We split our daily activities between the real and the digital realm. More and more frequently we go shopping virtually on the internet, go to the library on the internet, meet and chat with people over the internet, manage our finances, play, plan our entertainment, and even date through the information superhighways. These profound transformations of our life-style demand a new architecture that supports these new modalities of communication and living. Space needs to be redesigned to favor information exchange through video walls, across portable devices, and private-eye displays. Computation and sensing will move from computers and devices into the environment itself. The space around will increasingly be instrumented with sensors and displays, to reflect the diffused need to combine together the information space with our physical space. "Augmented reality" and "mixed reality" are the terms most often used to refer to this type of media-enhanced interactive spaces.

Several scenarios arise from the encounter and blending of media design and architectural disciplines [2]. Yet architecture's agenda needs to encompass not just the design of new media- and information-enhanced spaces, but should also extend itself to investigate natural modalities of human-computer interaction which facilitate communication through cyberspace [3][4]. Indeed still today, the interfaces available for people to communicate electronically are limited to the primitive and low-bandwidth keyboard and mouse attached to desktop or mobile computers.

This paper describes technological platforms built at the MIT Media Lab, through 1994-2002, that contribute to defining new trends in architecture that merge virtual and real spaces, and are reshaping the way we live and experience specifically the museum, the theater, the house, and the modern city. These platforms are grounded in research in real-time computer vision based human-computer interaction, as well as sensor fusion, and mathematical modeling of perceptual intelligence. Our focus is in narrative spaces, that is sensor-enabled, people-driven, media-augmented interactive indoors or outdoors spaces that convey information as (audio-)visual micro-stories or more simply as three dimensional information landscape visualizations.

This paper also wishes to highlight that, in the author's view, it is not a coincidence that the contribution to the new architecture for the information society illustrated in this paper comes from within a research group with a strong technical and scientific background, combined with creativity, a sense for architecture and space design, knowledge of filmmaking, and attention towards social change and needs. Specifically, the author's knowledge of statistical modeling, image processing, Bayesian networks, has enabled her and her collaborators to build a whole series of platforms and experiment with various scenarios of interactive spaces, to iterate the design process several times as needed, to progressively adapt the science and technology of interaction to the emerging design issues, so as to bring both the architectural and the technical aspects of the presented projects to the desired level of quality and performance.

2. Enabling Technologies

The problem, in my opinion, is that our current computers are both deaf and blind: they experience the world only by way of a keyboard and a mouse. Even multimedia machines, those that handle audiovisual signals, as well as text, simply transport strings of data. They do not understand the meaning behind the characters, sounds, and pictures they convey. I believe computers must be able to see and hear what we do before they can prove truly helpful. … To that end, my group at the Media Laboratory at the Massachusetts Institute of Technology has recently developed a family of computer systems for recognizing faces, expressions, and gestures. The technology has enabled us to build smart rooms … furnished with cameras and microphones that relay their recordings to a nearby network of computers. The computers assess what people in the smart rooms are saying and doing. Thanks to this connection, visitors can use their actions, voices and expressions – instead of keyboards, sensors or goggles – to control computer programs, browse multimedia information or venture into realms of virtual reality.
Alex Pentland, head of the Perceptual Computing Group at the MIT Media Lab, in: Scientific American, April 1996, pg 68 and 71.

The architect who wishes to reshape our surrounding space and body, and transform them into technology-augmented devices for information exchange and communication needs: sensors that are reliable and robust, and (mathematical) modeling tools which allow the system to understand the public's intentions and coordinate a narration. Information authoring tools need to be able to take input from people, and deliver a (personalized) story articulated not only over time but also over space. Just as humans use vision as their main sensing modality to perceive and understand their surroundings, the narrative spaces here presented use predominantly real time computer vision to locate people in space and understand what they are doing. This section offers a brief overview of the technologies and requirements the author believes are important to enable people-driven narrative space design. These are the technologies utilized to build the narrative spaces presented in the following section.

2.1. Sensing

Applications such as unencumbered virtual reality interfaces, performance spaces, and information browsers, all have in common the need to track and interpret human action. The first step in this process is identifying and tracking key features in a robust, real time, and non intrusive way. Computer vision is a tool capable of solving this problem across many situations and application domains. By use of real-time computer vision techniques [5][6][7] we are able to interpret the people's *posture*, *movement*, *gestures*, and *identity*. Wren and others [5] have shown that a system which has an image based two dimensional description of the human body as a set of adjacent color regions (head/torso/hands/feet), a MAP estimator for color pixel classification, and a Kalman filter applied to the features to track, is a very powerful tool to mathematically and computationally describe the human body in motion in real time. Similar maximum likelihood statistical approaches are also effective in stereo vision tracking to locate body features more accurately in 3-D space, when pointing direction, and accurate depth information are needed. Hidden Markov Models and more recently Bayesian networks, have been successfully used to classify human movements and gestures [8][9].

2.2. Robustness of multimodal perception

Robust sensing is the premise for the correct interpretation of the user's intention. Mono-sensor applications which rely on one unique sensor modality to acquire information about people are brittle and prone to error. For how well that one sensor works individually, whether that be a camera, or a radar, or an electric field sensor, it only provides the system with a single view of what is going on. In order for a body driven interactive application to offer a reliable and robust response to a large number of people on a daily basis, as needed in a museum, or to meet the challenges of the variable and unpredictable factors of a real life situation, we need to rely on a variety of sensors which cooperate to gather correct and reliable measurements on and about the user. Cooperation of sensor modalities which have various degrees of redundancy and complementarity can guarantee robust, accurate perception [10]. We can use the redundancy of the sensors to register the data they provide with one another. We then use the complementarity of the sensors to resolve ambiguity or reduce errors when an environmental perturbation affects the system.

2.3. Context-based data interpretation

To make good use of reliable measurements about the user, we need to be able to interpret our measurements in the context of what the user is trying to do with the digital media, or what we actually want people to do to get the most out of the experiences we wish to offer. The same or similar gesture of the public can have different meanings according to the context and history of interaction. For example the same pointing gesture of the hand can be interpreted either as pushing a virtual character, or more simply, as a selection gesture. In a similar way, the system needs to develop expectations on the likelihood of the user's responses based on the specific content shown. These expectations influence in turn the interpretation of sensory data. Following on the previous example, rather than teaching both the user and the system to perform or recognize two slightly different gestures, one for pushing and one for selecting, we can simply teach the system how to correctly interpret slightly similar gestures, based on the context and history of interaction, by developing expectations on the probability of the follow-on gesture. In summary, our systems need to have a user model which characterizes the behavior and the likelihood of responses of the public. This model also need to be flexible and should be adaptively revised by learning the user's interaction profile [11][18].

2.4. Narrative engines

It is difficult to produce compelling applications simply by direct mapping of sensor measurement inputs with digital media output. While this strategy may work for very simple interactive environments, it is not effective to orchestrate digital information effectively.

Many current interactive systems are defined by a series of couplings between user input and system responses. The problem with these systems is that they are often repetitive: the same action of the participant always produces the same response by the system. Alternatively, most existing CDROM titles are scripted: they sequence micro-stories in multi-path narrative threads. While the content presentation in these applications tends to be more engaging, they often impose a rigid interaction modality and become boring after a while. The participant's role is confined to clicking and choosing the sequencing of the narrative thread without real engagement or participation in the narrative. In order to create compelling narrative spaces we need to be able to simulate encounters between the public and the digital media acting as a character. To accomplish this goal we need to be able to model the story we wish to narrate in such a way that it takes into account and encompasses the user's intentions and the context of interaction [11]. Consequently the story should develop on the basis of the system's constant evaluation of how the user's actions match the system's expectations about those actions, and the system's goals.

These guidelines have driven the research described below on smart rooms [3][figure 3], smart desks [4][figure 4], and wearable computing, with special emphasis on interactive information presentation, digital storytelling, and cultural communication.

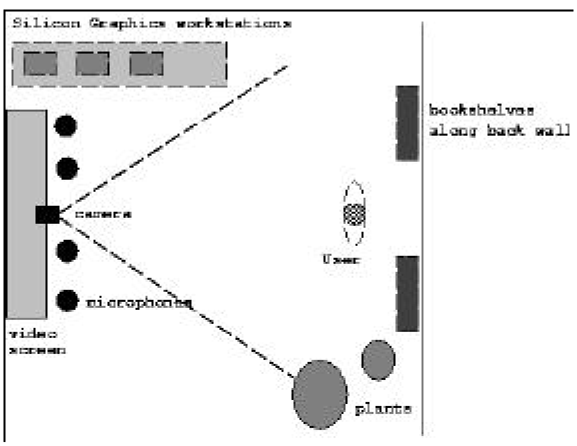

Figure 3. Smart room setup including a single camera for body tracking, a microphone array for speaker identification, and a large projection screen for content viewing

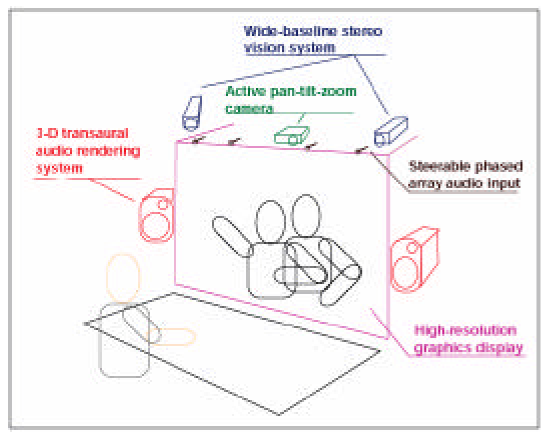

Figure 4. Smart desk setup with stereo vision, active camera for face expression recognition, microphone for speech recognition, and a large screen

3. From theme parks to culture parks: a family of narrative spaces

Now by embedding intelligence and interconnectivity in material products and creating systems of tags and sensors… we can construct spatially extended smart spaces from collections of interacting smart objects. Real desktops, rooms, and other settings – rather than their electronically constructed surrogates – can begin to function as computer interfaces … As a result, our actions in physical space are closely and unobtrusively coupled with our actions in cyberspace. We become true inhabitants of electronically mediated environments rather than mere users of computational devices.
William J. Mitchell, Dean of MIT's School of Architecture and Planning, in: e-topia, pg. 43

This section briefly describes a full generation of interactive spaces and platforms of interaction the author built at the MIT Media Lab through 1994-2002. While the reader will find more detail on each of these in the bibliography, the purpose of the following presentation is to illustrate the family of body driven interfaces for smart spaces in its entirety. This will serve as a basis to for the next section in which the author comments upon how the collection of such interaction platforms constitute a set of paradigmatic setups leading towards a renewed mixed-reality architecture for the information society.

3.1. Video Wall and interactive carpet: MetaSpace

MetaSpace [12] [figures 5 and 6] is large scale installation which uses two projection surfaces: one vertical and one horizontal. The horizontal surface is a large map projected on the floor. People physically walk onto different locations of the floor map and trigger consequently the front surface projection to show the correspondent visual and auditory information. One can see the floor map projection like a mouse pad, the person walking onto the map like the mouse driving the system, and the vertical large projection screen as the computer display. A computer-controlled infrared camera detects people's presence and location on the floor map, as well as their pointing gestures (selection gestures) towards the objects displayed on the vertical screen. MetaSpace installations have been shown at Ars Electronica 98, SIGGRAPH 99, and are currently being installed in a museum setting. It is the extension of the author's previous work on Hyperplex [13].

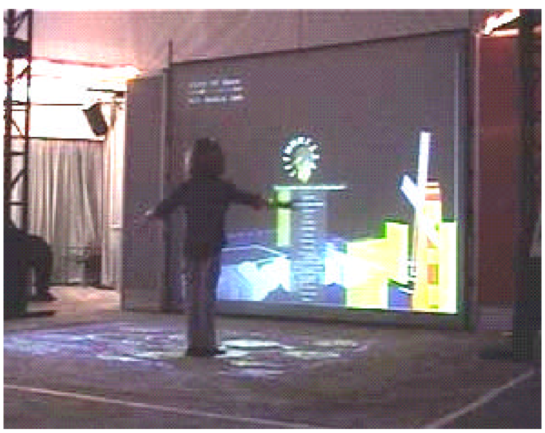

Figure 5. MetaSpace at the SIGGRAPH 99 Millennium Motel show.

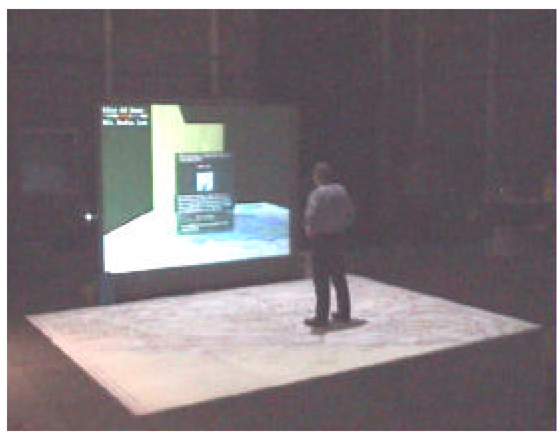

Figure 6. MetaSpace in the MetaCity Sarajevo setup, built for Ars Electronica 98

3.2. Presentation Table

The presentation table is an interactive horizontal display which narrates a story guided by the position of the objects on it. It is a playful interface which allows the public to explore the non linear contents of a book, CDROM, or audiovisual story [figure 7]. The table uses tag sensing and computer vision to locate and track physical content-selector objects on the table. Typically two types of objects are needed: a chapter-selector and an item-selector object. Visual narrative maps are associated to each chapter [figure 8]. When people place a chapter-selector object in the marked space in the center table, the visual table of contents for that chapter is projected on the table. When people select to learn more about one of the items on the visual content map, the corresponding text, image, audio, or video are displayed. Examples of the presentation table are: Unbuilt Ruins, an exhibit space, orchestrated by the table, which shows a variety of architectural designs by the influential XXth century

American architect Louis Kahn [14] and MOMA's Unprivate house exhibit's interactive table, modeled on the previous one.

Figure 7. The Unbuilt Ruins presentation table featuring projects by architect Louis Kahn

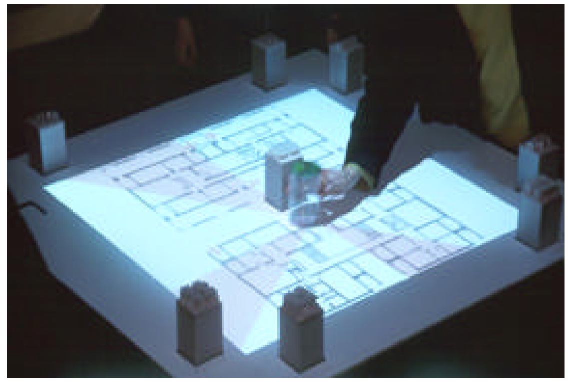

Figure 8. Chapter-selector objects around the table and item-selector object (green)

3.3. Gesture browsing through the information city: City of News

City of News is an immersive, interactive web browser that reads web pages from the internet and embeds them inside a three dimensional city-scape. It fetches and displays URLs so as to form skyscrapers and alleys of text and images through which the user can "fly" using body movements. Known cities' layout, architecture, and landmarks are given as input to the program and are used as organizing geometry and orientation cues [figure 9]. This virtual internet city grows dynamically as new information is loaded: following a link causes a new building to be raised in the district to which it belongs, conceptually, by the content it carries, and content to be attached onto its "façade". By mapping information to familiar places, which are virtually recreated, City of News stimulates in its users association of content to geography. The spatial, urban-like, distribution of information facilitates navigation of large information databases, like the Internet, by providing the user with a cognitive spatial map of data distribution [15]. To navigate this 3-D environment, users sit in front of a large screen and use hand gestures to explore or load new data. Pointing to a link will load the new URL building. The user can scroll up and down a building by pointing up and down with either arm. Side-pointing gestures allow users to navigate along an information path back and forth. Raising both arms drives the virtual camera above the internet city and gives an overall color-coded view of the urban-like information distribution [figure 10] [16].

Figure 9. Aerial view of City of News. Example based on the map of the city of Stuttgart

Figure 10. Gesture-driven navigation through the City of News in the smart desk

3.4. Telepresence: Virtual Studio

Virtual Studio is a 3-D set inside which people can meet and interact among themselves or with other 3-D characters. Thanks to advanced computer vision techniques, as in a magic mirror, participants see their full body video image composited in 3-D space – without the need for a blue screen background [17] [12] [figure 11]. Such a setup, requiring only a camera, a computer with a graphic card, and a fast network connection per participant, allows people to have access to real time compositing technology today available only in high end costly production studios. In addition to compositing the partcipants' video image inside a 3-D set the system uses gesture recognition techniques to give networked participants the added feature to modify, activate, and manipulate the elements of the 3D set in which they are immersed. The participant's image is subjected to all graphics transformations that can apply to graphical objects, including scaling. According to the participant's position in the space, his/her image occludes or is occluded by virtual objects in respect to the 3-D perspective of the virtual scene. Multiple people can connect from remote locations, therefore such setup can be used for collaborative storytelling, visual communication from remote locations, or game playing.

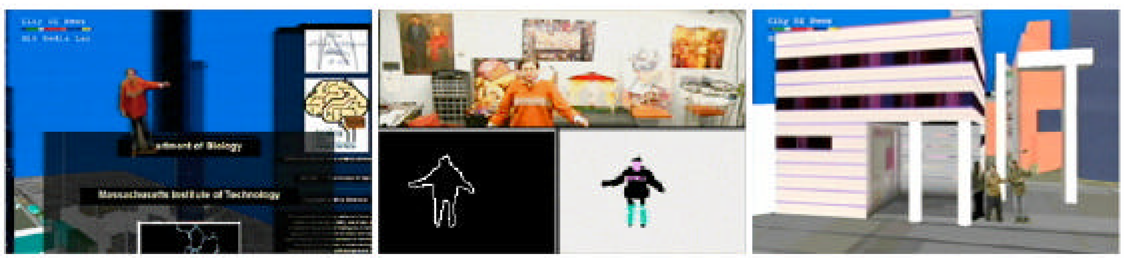

Figure 11. Virtual Studio: the user is composited in real time inside a 3-D set. In the last panel right: multiple people from remote locations are composited altogether in front of a virtual model of the MIT Media Lab.

3.5. Responsive Portraits

Responsive Portraits [18] [figure 12] challenge the notion of static photographic portraiture as the unique, ideal visual representation of its subject. A responsive portrait consists of a multiplicity of views – digital photographs and holographic 3D images, accompanied by sounds and recorded voices – whose dynamic presentation results from the interaction between the viewer and the image. The viewer's proximity to the image, head and upper body movements elicit dynamic responses from the portrait, driven by the portrait's own set of autonomous behaviors. This type of interaction reproduces an encounter between two people: the viewer and the character portrayed. In this installation the whole notion of "who is watching who" is reversed: the object becomes the subject, the subject is observed.

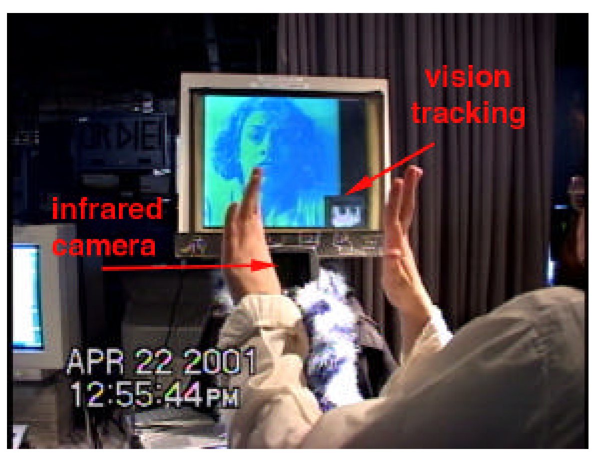

Figure 12. Responsive Portraits installation

3.6. Museum Wearable and Wearable Cinema/Wearable City

The museum wearable is a wearable computer which orchestrates an audiovisual narration as a function of the visitor's interests gathered from his/her physical path in the museum and length of stops [19] [figures 13, 14]. The wearable is made by a lightweight and small computer that people carry inside a shoulder pack. It offers an audiovisual augmentation of the surrounding environment using a small, lightweight eye-piece display (often called private-eye) attached to conventional headphones. Using custom built infrared location sensors distributed in the museum space, and statistical mathematical modeling, the museum wearable builds a progressively refined user model and uses it to deliver a personalized audiovisual narration to the visitor. This device will enrich and personalize the museum visit as a visual and auditory storyteller that is able to adapt its story to the audience's interests and guide the public through the path of the exhibit. Wearable City extends the previous application outdoors, to the city, using GPS location sensing. Wearable cinema explores the idea of a movie distributed in space and time and whose segments are triggered by the viewer's path in a theme park or city quarter [20].

Figure 13. The Museum Wearable worn by a visitor at the MIT Museum

Figure 14. The Museum Wearable: an explanatory movie clip plays as the visitor approaches a printed photograph of an artwork on display

3.7. DanceSpace and Improvisational Theater Space

When applied to the stage, our work augments the expressive range of possibilities for performers and stretches the grammar of the traditional arts rather than suggesting ways and contexts to replace the embodied performer with a virtual one [21]. In dance, the author has conducted research towards musical and graphical augmentation of human movement. This has led to DanceSpace: a stage in which music and graphics are generated on the fly by the dancer's movements. A small set of musical instruments is virtually attached to the dancer's body and generates a melodic soundtrack in tonal accordance with a soft background musical piece. Meanwhile, the performer projects graphics onto a large backscreen using the body as a paint brush [figure 15]. In theater, the focus done work in gesture, posture, and speech augmentation. In Improvisational TheaterSpace a human actor can be seen interacting with his own thoughts in the form of animated expressive text projected on stage. The text is just like another actor able to understand and synchronize its performance to its human partner's gestures, postures, tone of voice, and words [figure 16].

Figure 15. DanceSpace

Figure 16. Improvisational Theater Space

The next section attempts to draw scenarios on how the interaction platforms and instrumented spaces described above will likely influence and hopefully enrich the way we learn, explore, entertain, live, and specifically on how the traditional spaces that house such experiences are being reshaped to accommodate for the social changes in act.

4. Narrative Spaces

We will characterize cities of the twenty-first century as systems of interlinked, interacting, silicon- and software-saturated smart, attentive, and responsive places. We will encounter them at the scale of clothing, rooms, buildings, campuses, and neighborhoods, metropolitan regions, and global infrastructures.
William J. Mitchell, Dean of MIT's School of Architecture and Planning, in: e-topia, pg. 68

People experience their lives as a narrative. Amongst cognitive psychologists, Jerome Bruner stressed the importance of story, as the means which structures our perception and communication [22]. He reminded us that thinking cannot be reduced to mere information processing and sorting into categories and that narrative is our main instrument of making - meaning, the embodiment of culture, communication, and education. The history of architecture offers innumerable examples of places which embed and narrate a story through their spatial layout and décor. By looking at the sequence of floor plans of historical buildings through the centuries, from the Greek temple, to the Roman church, the medieval dome through today, we understand how a rectangle, a circle, a cross, or other more complex figures, transmit a message through the centuries. This message is a story about how people through times relate to life, nature, and spirituality.

The new information society architecture can more explicitly embed stories and information in its structure, thanks to the tools offered to us by the digital revolution. Following are a few scenarios relative to changing places: the museum, the city, the house, the theater, that draw from the examples presented in the previous section.

4.1. The museum

Museums have recently developed a strong interest in technology, as they are more than ever before in the orbit of leisure industries. They are faced with the challenge of designing appealing exhibitions, handling large volumes of visitors, and conserving precious artwork. They look at technology as a possible partner which can help achieve a balance between leisure and learning as well as help them be more effective in conveying story and meaning. Technology can help construct a coherent narrative of an exhibit for the visitor by creating experiences in which the objects on display narrate their own story in context [14]. Using interactive techniques embedded in the physical space museums can present a larger variety and more connected material in an engaging manner within the limited space available. They can also enrich and personalize the visit with wearable computers which act as a visual and auditory storyteller that guide the public through the path of the exhibit. The presentation tables will be used a playful interface for the public to access and explore the body of facts, content, and stories of the exhibit. The MetaSpace can be installed as an introductory immersive cinema space. Responsive portraits show artwork that reacts to how people approach it and is capable of explaining its origin and making. All these systems enhance the memory of the visit and help build a constructivist-style learning experience for the public.

4.2. The city

In the last decade, the architectural landscape of the contemporary city has been undergoing a profound transformation. When we drive from one city to the next, when we wander in the city center, when we drive to the airport, large billboards with printed images or large LCD screens show us publicity, entice us, talk to us, inform us about our banking, clothing, insurance, entertainment, eating options. These billboards are embedded in the city architecture, and have become integrated in the visual appearance and profile of the city-scape. Most of us are no longer surprised to see building-size images decorate facades juxtaposed between skyscrapers or even historical buildings. This phenomenon has invested modern metropolis, notably Tokyo [figure 17], Los Angeles, along "The Strip", in Sunset Boulevard, a route which joins the city with Santa Monica [figure 18], New York, particularly around the Times Square area [figure 19] Yet it does not spare more classical European cities such as Milan [figure 20], Paris, or Berlin. Especially at night , Times Square and its surroundings evoke science fiction cities a la Blade Runner : the city becomes a spectacle, a visual symphony, a multi-screen receptor and display of information of all sorts. Only recently artists [23] and architects [www.streetbeam.com] have started to conceive and prototype experiences where the information flow involves communication between city billboards, passerbiers with PDA devices, and people at home connected to the internet. MetaSpace is in the process of being scaled to an outdoors experience where people walking on the carpet of light projected on a central sidewalk orchestrate images and information presentation embedded in the surrounding buildings [24]. The wearable cinema and wearable city projects add new flavor to existing research on PDA-guided tourism and entertainment.

Figure 17. Tokyo: Ginza.

Figure 18. Los Angeles: Sunset Boulevard.

Figure 19. New York: Times Square.

Figure 20. Milan: next to the city center.

4.3. The house

Compared to the enormous progress in miniaturization, computing power, and cost reduction of electronic equipment, very little progress has affected the house in the last few decades. Yet most homes today include an area, or table, with a computer that family members use for various tasks, most of them related to information browsing over the internet, communicating with friends, planning entertainment, and shopping. Soon however the current living room scenario in the home will change. In one corner a city-of-news-like gesture-browser will allow people to navigate information on the Net, represented as an evolving 3-D information city that appears in a large LCD "window over cyberspace". In another corner people could activate the virtual studio and see their video image composited, together with the ones of their remote correspondents, inside a chosen three dimensional chat room, in a virtual café. The hyperplex interface [13], together with a voice recognition system, interprets users' commands at need. In the adjacent room the kids are jumping around and making music with DanceSpace, while in the home office the presentation table assists the user with their next project.

4.4. The theater

Dance and theater performances, operas, musicals, cinema projections, talk shows, all take place in traditional spaces made by a stage on one end and the audience on the other end of the space. The lights go off and the spectator is typically passive for the duration of the show. Ongoing work by the author leads towards three different scenarios: one which augments and extends the expressive range of traditional performance, one which gives the public contextual information and explanation about what's happening on stage, and a much different one which involves technological support to bring traditional performance from the traditional stage-audience presentation setting, to the street or other unconventional performance places that allow for a more direct contact of the performer with the audience. DanceSpace, Improvisational theater space, or similar technologies will be integrated in the stage and will help create media-actors, a collection of digital expressive text, images, and video which co-act with human performers thanks to their sensors, perceptual intelligence, and context modeling abilities, as described in section 2. The presence of a public with wearable computers will also stimulate new kind of performances in which the public plays a more active role. In theater, for example, the author is interested in exploring how point-of-view transforms our perception of reality. The wearable can be used as a "semantic lens" to offer audience members a new, transformed interpretation of the story told by the performer. This lens provides a view-dependent reality augmentation, such that different people observing the show from different areas of the theater, are led to a different interpretation of the story told by the actors. Wearable street performance [25] will also contribute to change location and modalities of the contemporary performance arts.

These scenarios show how, in a non distant future, the prototypes described above will likely influence the changing design of traditional living, learning, and entertainment spaces. Other possible scenarios involve the classroom, the office, the retail store, cafes, etc. In the home the reading room will be connected to an electronic book which has the touch and feel of the printed book we are familiar with. The kitchen will be made of interconnected smart appliances which assist people in cooking. The architect's agenda in the next few years will have to include, develop, and work towards turning these types of scenarios into reality.

5. Conclusions: new challenges for today's architects

Traditional urban patterns cannot coexist with cyberspace … This will redefine the intellectual and professional agenda of architects, urban designers, and others who care about the spaces and places in which we spend our daily lives … This new agenda separates itself naturally into several distinct levels … We must put in the necessary digital telecommunications infrastructure, create innovative smart places from electronic hardware as well as traditional architectural elements, and develop the software that activates those places and makes them useful… To pursue this agenda effectively, we must extend the definitions of architecture and urban design to encompass virtual places as well as physical ones, software as well as hardware, and interconnection by means of telecommunications links as well as by physical adjacencies and transportation systems.

William J. Mitchell, Dean of MIT's School of Architecture and Planning, in: e-topia, pg. 8

This paper described a series of sensor-enabled, media-augmented, people-driven narrative spaces and highlighted the role of the technologies that are key in their conception and making. Scenarios are given for how the variety of such spaces and related hardware and software platforms can be used in, and influence the way we experience more traditional "narrative spaces" such as the museum, the theater, the house, and the city.

Another contribution of the paper is also to underline that technology is not simply hardware of software that the space designer and the media artist add to their projects to make them work. It is really not sufficient to wait for technologists to develop new modalities of interaction and man-machine communication in their laboratories, to later incorporate these in space design, as software that one buys at the store. The architecture of the information society is truly driven and informed by technology, which in turn shapes the architectural thinking and project development. Unless today's architects are able to shape the tools they need to produce new space designs, then their creations and aesthetics will always be limited by their technological competence. On the other end, technologists with a robust knowledge of people tracking and statistical modeling, blended with creativity and a sense for experience design and space design, seem to be in a better position than traditional architects to contribute to new trends in architecture.

To build narrative spaces, rather than stressing the importance of collaboration among people with different backgrounds and fields of competence, the author, based on her own education and experience, wishes to show that today's architect can also be in equal measure a scientist, an engineer, and a visual artist and communicator. The role and required competencies of the contemporary architect tend to create a new professional figure characterized by a mastery of disciplines today considered belonging to separate practices and teachings. Yet this new professional figure has old and profound historical roots. The European renaissance has given birth to two typologies of intellectuals: the scientist type, incarnated by Galileo, who first established rules for scientific experimentation and scientific method and the artist-engineer, incarnated by Leonardo, involved in a creative research equally informed by art and science. In modern times Moholy-Nagy, and more closely to MIT, Gyorgy Kepes represent models of the contemporary artist-engineer. While the Galileo-scientist type has been predominant in western culture since after the renaissance, the emergence of digital media favors the re-appearance of the artist engineer, equally versatile in artistic creation and engineering abilities.

The nature of the projects here presented stresses the importance of statistical mathematical modeling techniques and corresponding technologies, such as pattern recognition and machine learning, for the field of interactive space design. The author believes that the main concepts and tools of these disciplines should become part of the current language of the today's and tomorrow's architects because they are the basis for any reliable sensor interpretation and intelligence simulation by machines, both indispensable in the new architecture of the information society.

Acknowledgements

The prototypes presented in this paper were developed under the scientific direction of Alex Pentland, head of the perceptual computing group at the MIT Media Lab. The author is also grateful to Neil Gerschenfeld, head of the MIT Media Lab Physics and Media group, who more recently provided additional and complementary scientific guidance and support. Glorianna Davenport offered advice and financial support. Dean William J. Mitchell has offered helpful suggestions and encouragement. Several MIT undergraduates contributed through the years to the research presented in this paper. Their names are: Chloe Chao, Mike Hlavac, Jeff Bender, Teresa Hernandez, Manuel Martinez, Tracie Lee, Chin Yan Wong, Eric Hilton, Sarah Mendelowitz, Anjali D'Oza. Other collaborators include Tom Minka, Christopher Wren, Ali Azarbajeani, Nuria Oliver, Yuan Qi. All featured photographs are by the author.

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Generative Art 2002

Architectural Forms by Abstracting Nature

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Abstract

The structures in nature are great lessons for human study. Having been in development for several billion years, only the most successful structural forms have survived. The resourcefulness of material use, the underlying structural systems and the profound capacity to respond to a variety of climatic and environmental forces make natural form tremendous exemplars to human architectures. The wholeness of natural form indicates that the form and forces are always in some sense of equilibrium. In most of natural forms, the quality of equilibrium may be difficult to recognize. However, seashells are one of the natural forms whose functions are simple enough to be approximated by a simple mathematical relationship. The focus of this study was to understand the seashell form as applicable to human architectures. Digital methods are the language to analyze, create, and simulate seashell forms, as well as, suggest a variety of possible architectural forms.

1. The Study of Natural Forms

The study of seashells has a long history, starting with Henry Moseley in 1838 [1] and followed by many researchers such as Thompson [2], Raup [3, 4], Cortie [5], and Dawkins [6]. These researchers have outlined in a number of mathematical relationships that control the overall geometry of shells. Our interest centers on an investigation of natural forms as a starting point to generate architectural forms.

As documented by prior researchers, the seashell geometry can be expressed by four basic parameters. Figure 1 indicates these parameters that influence the shell forms.

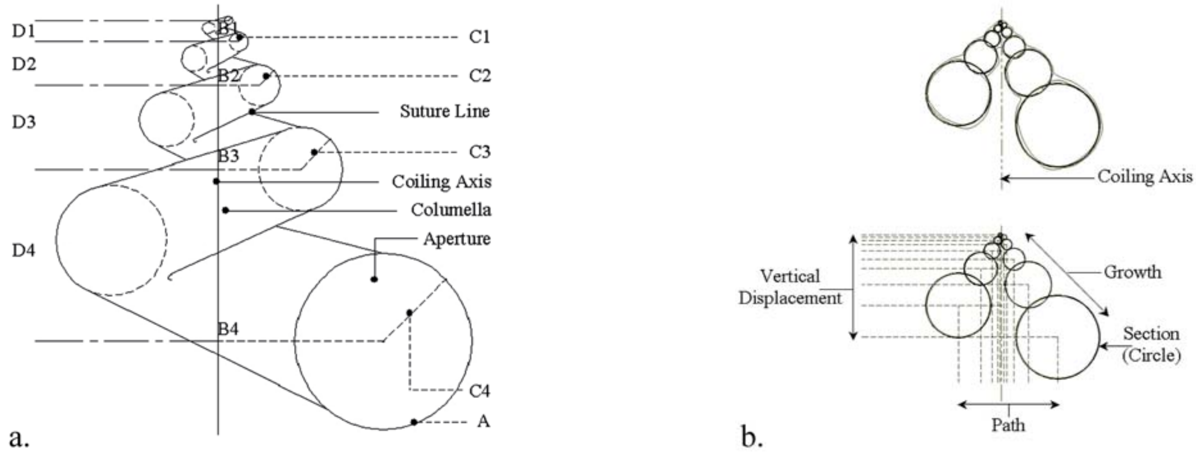

Figure 1. The four parameters.

As shown in Figure 1a, A is the shape of the aperture or the shape of shell section, B is the distance from the coiling axis to the center of the shell section, C is the section radius, and D is the vertical distance between sections. To understand the mathematical relationship of these four parameters, Figure 1b illustrates the measuring concept of one coiling shell of the gastropods class and Figure 2 illustrates its digital geometry reconstruction.

Figure 2. The wire frame and mesh model of selected seashell.

Each seashell can be reconstructed in a digital form with variations of the mathematical relationships among the four parameters. The result of a specific mathematical combination reflects the shell form for a specific seashell specie. In this study, the concept of creating architectural form originating from seashell geometry can be accomplished by applying these parameters to an architectural form interpretive exploring process.

Using mathematics as a tool of investigation in both the natural and architectural forms gives us an advantage of exploring multiple forms easily and allows us to implement new parameters into the mathematical framework. Architecture, which exists in a dramatically different environment from the seashell, has other parameters to be integrated during the architectural design process concerning its form. These parameters are designed to accommodate the practical requirements of architectural forms.

2. Abstracting Nature

The abstracting process combines three major components that influence the final result of an architectural form. These components are the seashell geometry properties, seashell structural properties and architectural properties.

2.1 Seashell Geometry Properties

There are four known parameters in the study of seashell geometry; path, section, growth and vertical displacement. Each parameter is represented by a specific mathematical curve in which it can be replaced with series of different mathematical curves to develop an architectural form. In the seashell form these mathematical curves are limited to those that appeared in the actual geometry of shell such as logarithmic spiral, circle and ellipse. In the architectural form the limitations are less, however, only mathematically defined curves are chosen in this investigation according to the fact that seashell form always exhibits a curvature. For a clearer understanding in replacing seashell parameters with other mathematical functions, the mathematical curves are divided in to two simple groups based on their mathematical properties; closed curves and open curves. Figure 3 illustrates the sample of closed and open curves and diagram indicates the use of each group.

2.2 Seashell Structural Properties

The actual shell geometry responses to any load outside by redirecting forces within a very thin section of shell structure along its natural multiple curvatures. Finally those forces are transferred to the supported area such as ground, rock or sand depending upon how the seashell positions itself in the environment. By acknowledging this structural phenomenon and understanding its weakness against tension forces, the compressive shell form suggests the possible structure of the architectural form beyond the existing forms of man-made shell structure. Its structural properties applied to architectural interpretations are included the shape of section, the overlapping section, and the support condition.

2.3 Architectural Properties

In architecture, there are some basic design criteria that architects and engineers have to take into consideration when developing building forms. In this investigation those criteria are treated as architectural parameters. These parameters emerge from architectural design principles that make architectural forms inhabitable. Without a specific requirement of an actual site and functions, the architectural parameters for this study can be set as ground condition, orientation, human scale and enclosure.

As architectural forms are developed the interpretation of these three major components yield the resultant of architectural form that contains the qualities of the seashell.

The architectural form generating concept adopts the four parameters from the seashell geometry and implements additional conditions based on architectural and structural properties into one mathematical framework. This mathematical framework then generates the result of the architectural form. Figure 3 illustrates the diagram of related parameters in various combinations that enable architectural form to be generated.

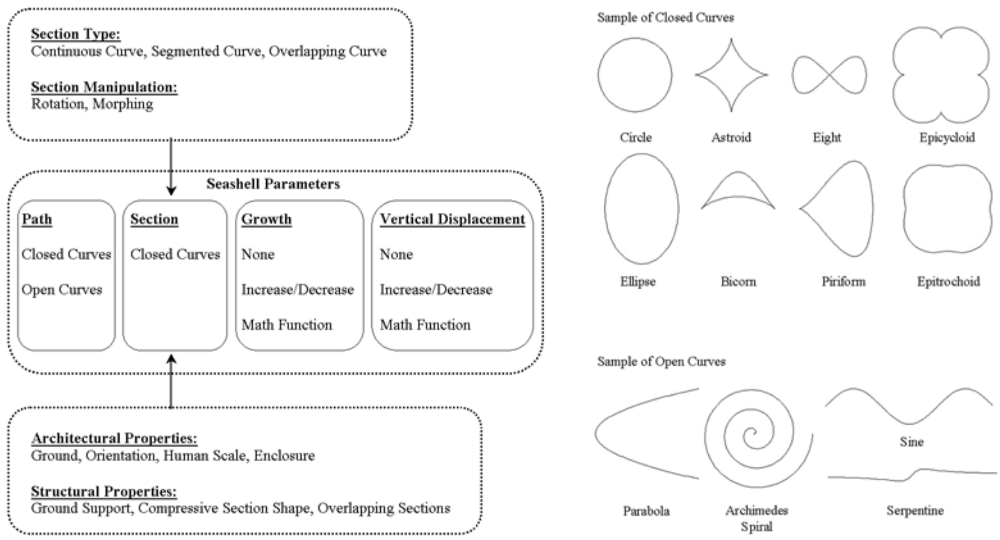

Figure 3. Architectural form generating diagram and mathematical curves.

To illustrate the possibilities of architectural forms generated in this process, samples of conventional and unconventional architectural forms are presented in Figure 4.

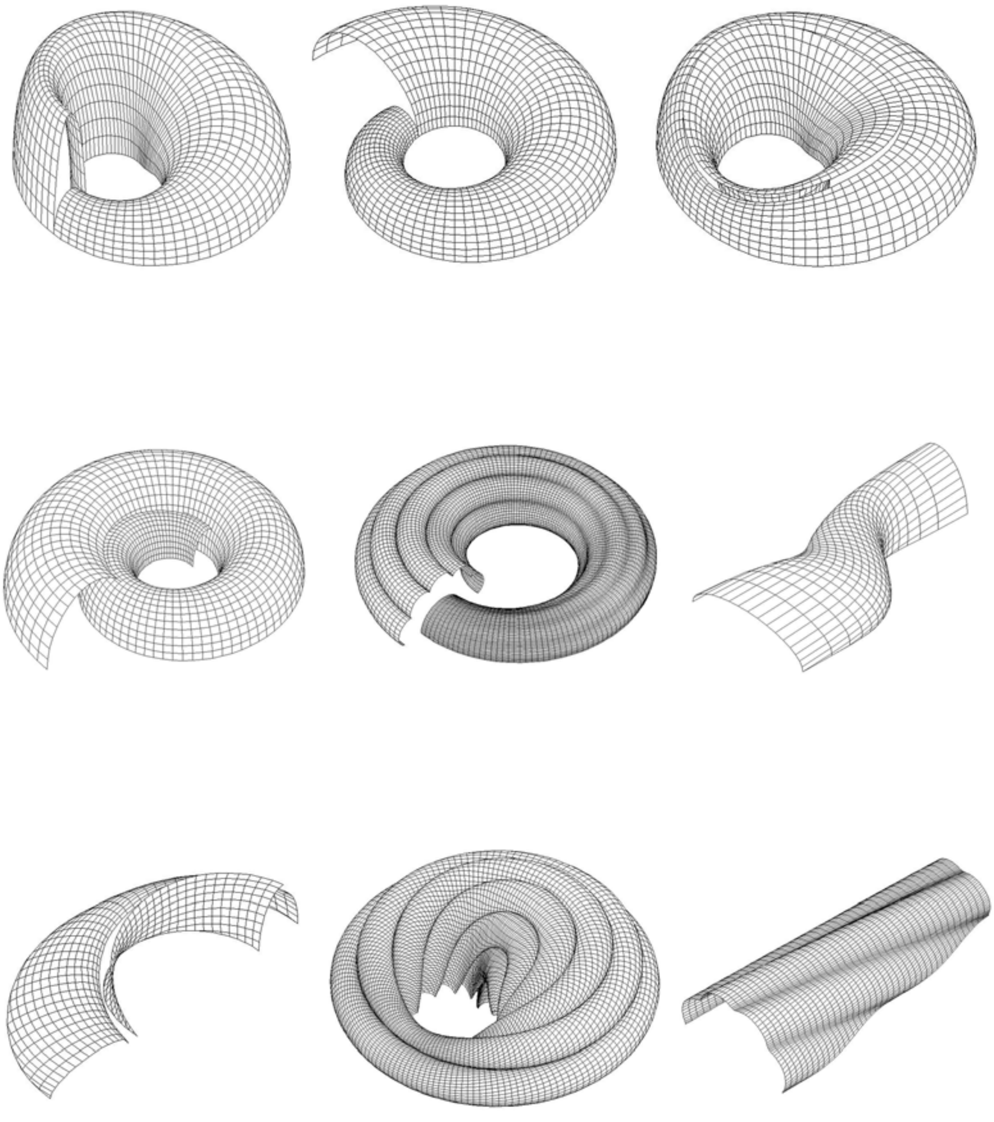

Figure 4. Sample of generating forms.

3. Architectural Applications

The result of forms developed by this process can be applied for specific architectural functions. Figures 5 exhibit the idea of how these forms can be used as architectural applications. Each form displays a virtual quality of architecture and is ready to be developed further to a real architecture with proper material and structural system selection.

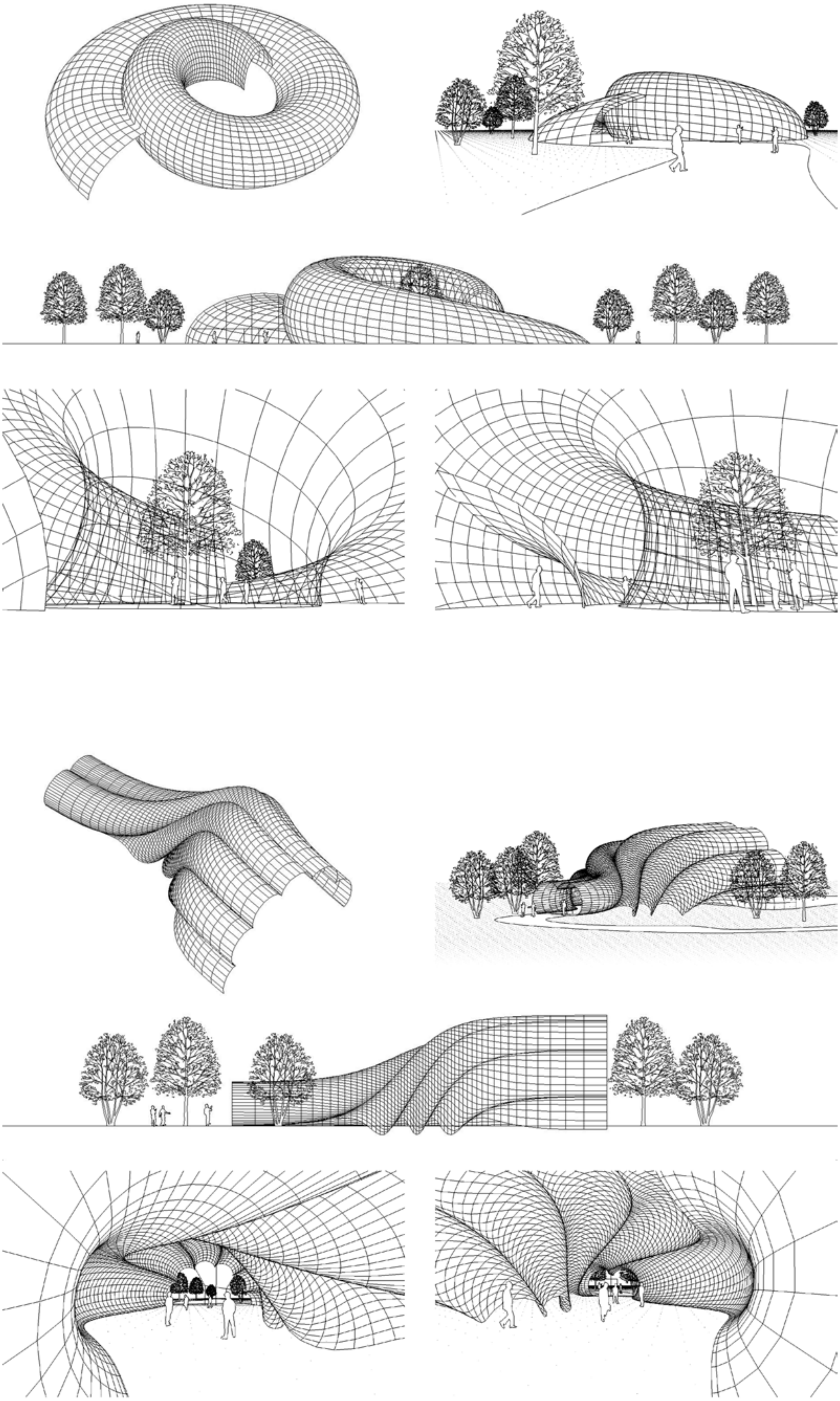

Figure 5. Sample of the architectural applications.

4. Observation and Conclusion

This research concluded that the value of the study of nature is not only for its power of inspiration and influence, but also for its abstract geometric properties. If the abstract properties can be described by the mathematical relationship, they can then be developed into a built form. The translation of abstracted nature in conjunction in concrete mathematical terms and by applying prerequisite architectural considerations is the fundamental concept of this form development.

The value of this research is the process of developing mathematically definable models into an architectural form. The process is flexible enough to be adjusted to a variety of parameters according to the specific requirements of each architectural project. The results are a family of architectural forms based on one simple mathematical comprehensive relationship.

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The Evolving Role of the Artist

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Abstract

For more than a decade the author has designed and used algorithmic systems to produce artworks that incorporate generative and evolutionary concepts, forms and processes. This work has demonstrated that algorithmic aesthetic processes and products can be effectively created and modulated by both human beings and non-human systems. However, this work has also raised important questions such as:

- What role can the individual human artist play in a cultural economy based upon industrialized generative processes and non-human systems?

- How can artists integrate standardized scientific languages and algorithmic processes into personal visions and expressive languages?

- How can artists capture their personal creative processes and encapsulate these processes in industry standard systems and software; and should they do so?

- How might the generative systems and products created by human and non-human artists function and evolve in the larger social context?

To address these questions, in this paper the author uses examples taken from his past and present artwork to illustrate the opportunities and pitfalls presented by computerized generative aesthetic processes and tools. In addition, the author offers a set of conjectures intended to help clarify issues such as: the evolving role of the artist as a producer of knowledge and form, and the value and appropriate structure of personalized computer languages for artists.

1. Introduction

During the past decade or so, I created a number of generative systems that I have used to produce computer-based, real-time, data-driven, human-scale, art installations and performances. These works embody concepts and images that grew from my eclectic synthesis of evolutionary concepts, algorithmic aesthetic processes, and art historical practices and precedents. John Dunn, an artist-programmer who I have had the good fortune to collaborate with for many years, created the computer tools and systems that I use to build and program my personal generative systems. He also composed the DNA-driven synthesized music that often accompanies my work.

It is worth noting here that John Dunn and I have both worked with Sonia Sheridan, Professor Emeritus of the School of the Art Institute of Chicago, and our work has been influenced by her approach to generative systems. For example, we share her belief that artists should be empowered to explore new forms of expression and production using contemporary industrial and scientific knowledge, systems and practices. We also share her conviction that artists must be able to develop unique personalized systems of practice and notation that complement the industrial practices and tools. We believe that artists can best explore and express their multidimensional, all-too-human, and often pre-verbal ideas by using multiple complementary creative systems that foster the integration of social scale and personal scale knowledge.

The purpose of this paper is to introduce the reader to some of this work and to illustrate some of the opportunities, pitfalls and questions that emerged from using computerized generative aesthetic processes and tools. To this end, I will discuss three different bodies of work, each built upon a unique computing platform and set of aesthetic concepts. I will also discuss the interaction between the concepts embedded in the tools, the concepts that the artist brings to the work, and the concepts that emerge from the interaction of the tools and the work. While some of these works and the computing platforms they were built on may appear visually archaic today, I find that many of the concepts and lessons they embody are still very relevant to contemporary generative art practice.

2. *Dark Matter* and *Tree of Life*

Dark Matter and *Tree of Life* are two installation artworks I created in 1994-1995 using the Vango software system created by John Dunn in 1991-1992. These works were presented as human-scale, immersive, real-time, computer animated installation performances with accompanying DNA-driven synthesized music [1].

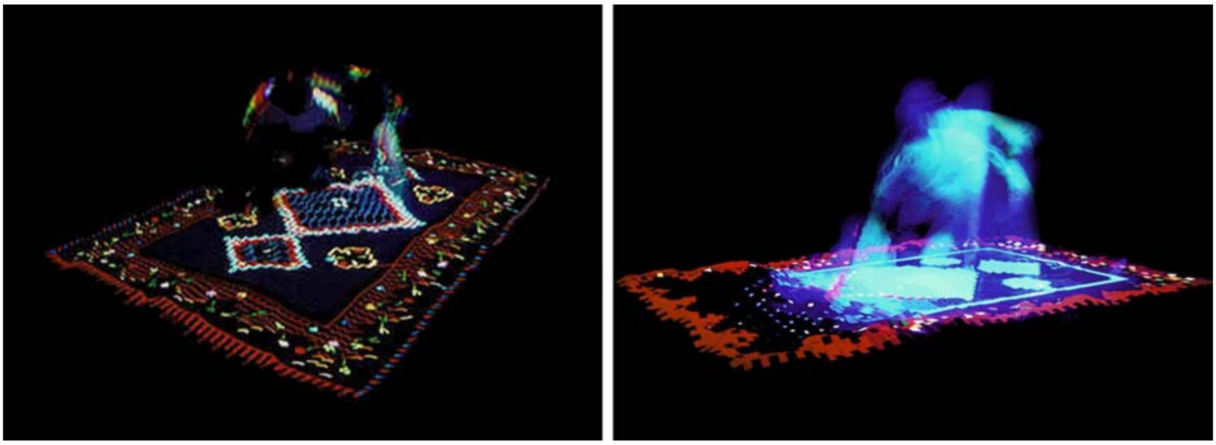

Figure 1. Still images taken during an animated *Dark Matter* installation-performance

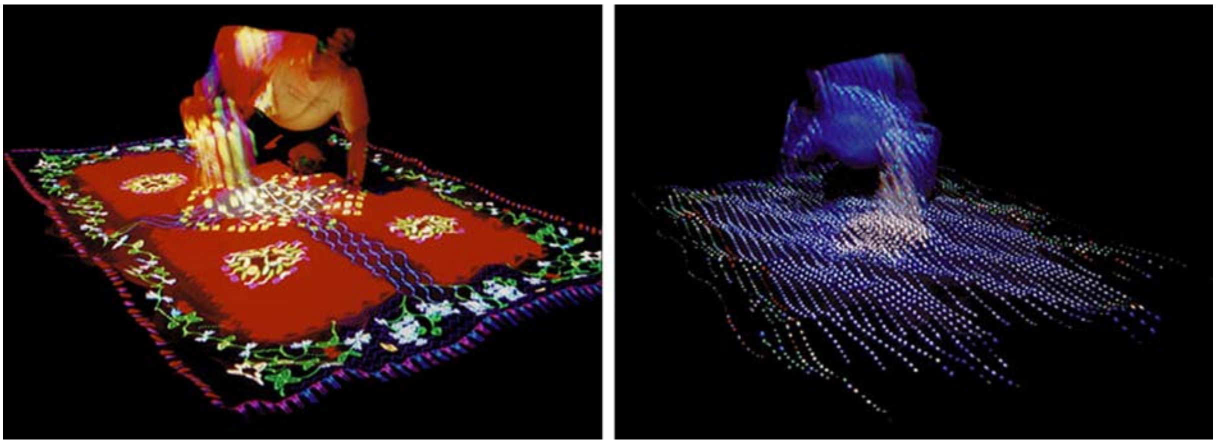

Figure 2. Still images taken during an animated *Tree of Life* installation-performance

Vango was a DOS-based, pre-web, real-time, animated hypertext system that used ASCII character graphics in innovative ways. John built Vango using character graphics because at that time he was constrained by a non-competition agreement that prevented him from developing ‘real’ graphics systems; i.e. pixel graphics systems like Lumena. Of course, it was precisely because Vango was not a ‘real’ graphics system that it was so interesting and revealing to work with.

For example, because Vango used character graphics, which were stored in a PC's hardware ROM, it was incredibly fast compared to pixel graphics systems of the time and therefore the creative feedback loop between the artist and the animated images was also very tight and fast. Of course, in addition to speed Vango had other unique structural and creative properties. Vango let an artist:

- 'Paint' in a 2 dimensional hyperspace using ASCII characters and using each character's CFB[2] attributes independently or in any combination.
- Combine multiple images in unique ways based on the CFB attributes of the characters that made up the images as well as on a transparent character attribute.
- Create user or system-activated buttons that jumped or slid the user to new locations in the 2D hyperspace while combining images in real-time.
- Create user or system-activated buttons that triggered MIDI events.
- Save and return to specific states of the system and therefore save and return to various states of the images, hyperspace trajectories, and CFB combinations.

After working with Vango for some time, I developed a whole set of generative processes that exploited Vango's capabilities and allowed me to develop a unique set of images and concepts. However, for the purposes of this paper, I think the system's great speed, its ability to combine sliding images in real-time, and its ability to individually set character CFB attributes are particularly worth mentioning.

Figure 3. Vango menus, color palette, CFB selector, navigation pads, and ASCII palette

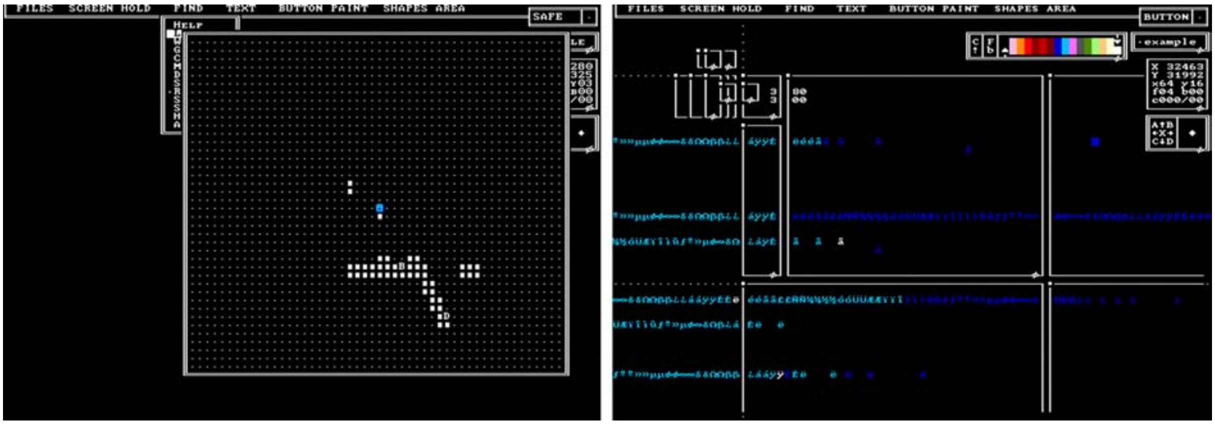

Figure 4. Vango hyperspace map and jump-slide-MIDI buttons

Because Vango could animate all 4000 characters on the 80 column by 50 row VGA screen at the rate of 50 characters per second when running on a 486 PC with local bus video, I was able to develop ‘herds’ of animated objects on my desktop PC. Each character position on the screen became an individual animation that was generated by sliding a series of characters past that position while ‘fixing’ the viewers eyes with stable color structures enabled by the CFB controls. This technique made it possible for a viewer to see animated characters rather than sliding characters. I could also group the sliding characters into visually meaningful units or herds that would, from the viewer’s perspective, visually unite or break apart depending upon how I painted the interacting images and how I set up the hypertext button slide trajectories that combined the images. In any event, the animation effect was so strong that some viewers reported becoming seasick from the intense visual motion. (See the right hand image in figures 2 and 5 for static examples.)

Figure 5. Vango ASCII image structure examples

Having such a fast system also meant that I could use musical ideas to structure my visual processes and that I could involve viewers in the work in novel ways. For example, I used a musical theme and variation structure to create the complex motion trajectories that animated the work's imagery. In addition, I used the fast graphics to create lines in the images that would scan and articulate the bodies of any viewers who were seated in the work. Vango's speed, coupled with its ability to change images, trajectories, colors, CFB interactions, and MIDI events on the fly, allowed me to produce a remarkably wide range of image structures and viewer experiences using a very limited set of generators.

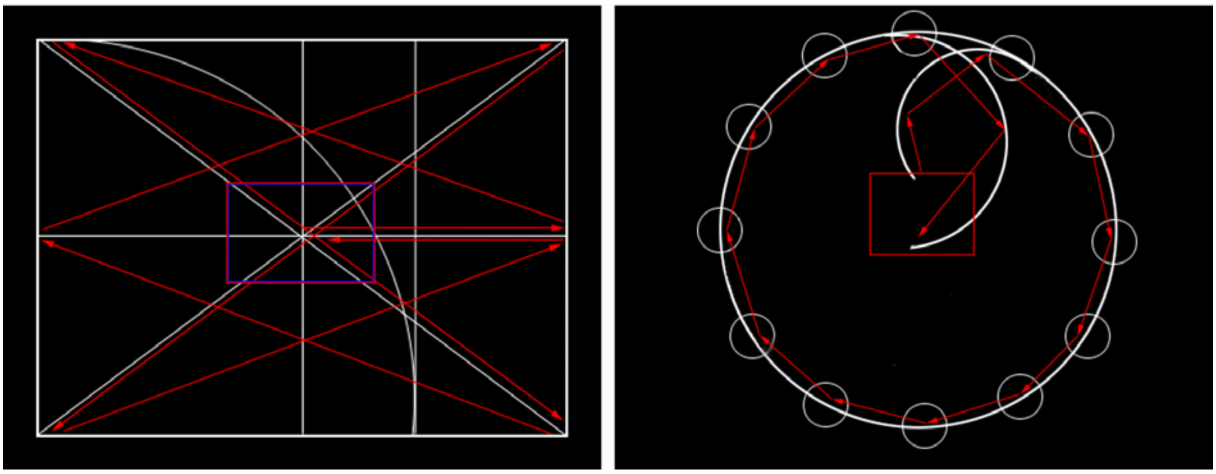

Figure 6. Hypertext sliding motion trajectory maps from *Dark Matter* and *Tree of Life*

While Vango certainly enhanced my creative process, the system also stimulated me to explore a number of genetic art ideas. For example, because Vango used the characters' CFB attributes when combining images as they slid or jumped through the hyperspace, Vango implicitly embodied a simple but dynamic genetic system. And, because Vango provided the ability to save and return to specific system states, it also provided a glimpse into an evolving genetic system in which my artistic decisions acted as the selective pressures. In essence, at any given point in the history of an artwork, I would use Vango to create a mother image and a father image. Then I would build the trajectories and assign the CFB settings that would combine the parent images' characters. The resulting real-time animation and combination process would produce a set of child images; or more accurately, a herd of child character sequences. I would repeat this process many times, then move back and forth in time to view the different genetic imaging systems I had created.

I found this whole process absolutely fascinating because I could use a simple, affordable, understandable, high-feedback, and animated computer imaging system to explore my multidimensional ideas about genetic imaging, structural transparency, fractal time, image evolution, process evolution, and the evolution of metaphor, to name a few. Moreover, at a time when ‘real’ genetic animation systems could not realistically run on an artist’s desktop PC, I could actually work on my little 486 with herds of ‘object-oriented’ ‘genetic’ animations that lived in a large hyperspace and ‘interacted’ with the viewer. My imagination went wild.

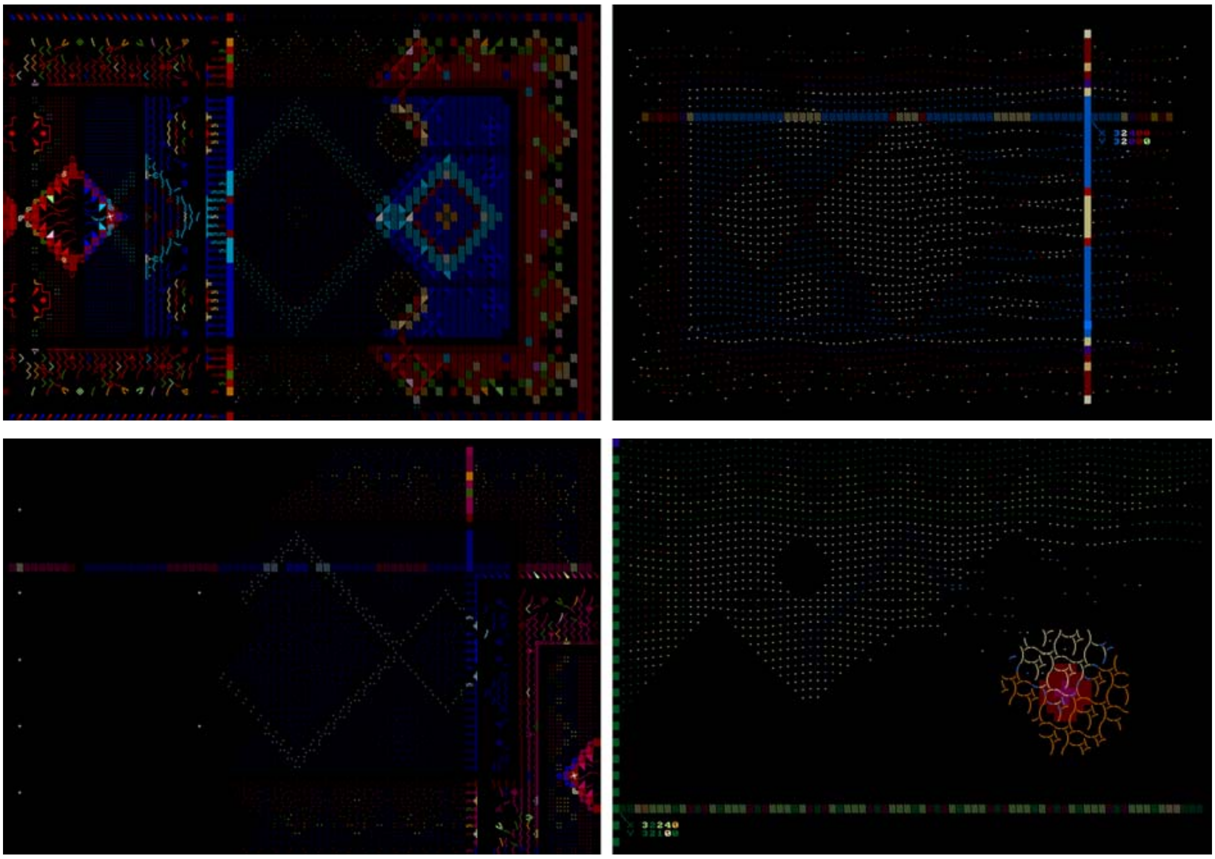

Figure 7. Various CFB 'genetic' interactions from *Dark Matter*

However, Vango had another structural property that made it interesting genetically; it used indexed characters and colors to create images. By using indexed entities to create images, Vango implicitly created a simple system in which there was a distinction between the image’s genotype and its phenotype. The genotype of a Vango artwork consisted of the character and color indexes that made up the images and the hard-coded button trajectories. The phenotype of the work was generated when the images were played and projected on a particular surface using a particular font and color palette. (See the right side of figures 1 and 7.) This aspect of Vango was also fascinating to me because I could create different ‘strains’ of an artwork simply by varying any combination of its CFB genetics, its font, and its projection environment.

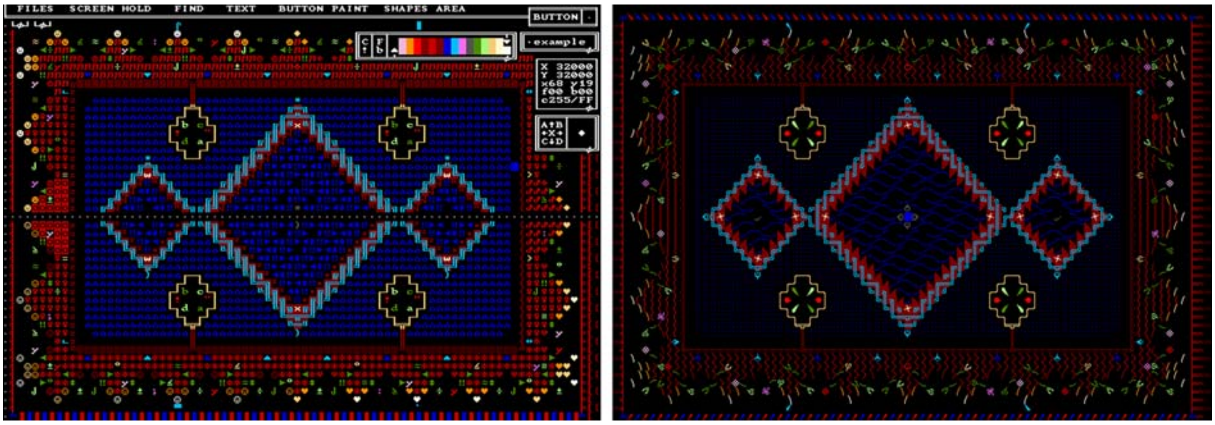

Figure 8. Genotype (visible as default phenotype) and screen phenotype from *Dark Matter*

Of course, using Vango also had its pitfalls, two of which deserve mention here. The first problem was that the more successful I became at producing interesting animations based on unique character fonts, the more difficult it became to actually use the system. This is because Vango, like most DOS ASCII applications, used the same character set for authoring the artwork and playing the artwork. As a result, the more I successfully modified the character fonts for aesthetic effect, the more difficult it became to read the Vango menus and tools, and the more difficult it became to read DOS screens. In fact, John and I used to joke that my pieces looked as if the were written in Klingon, an imaginary alien language used in the television series Star Trek. In the end, I had to memorize all the Vango menus because they had become unreadable.

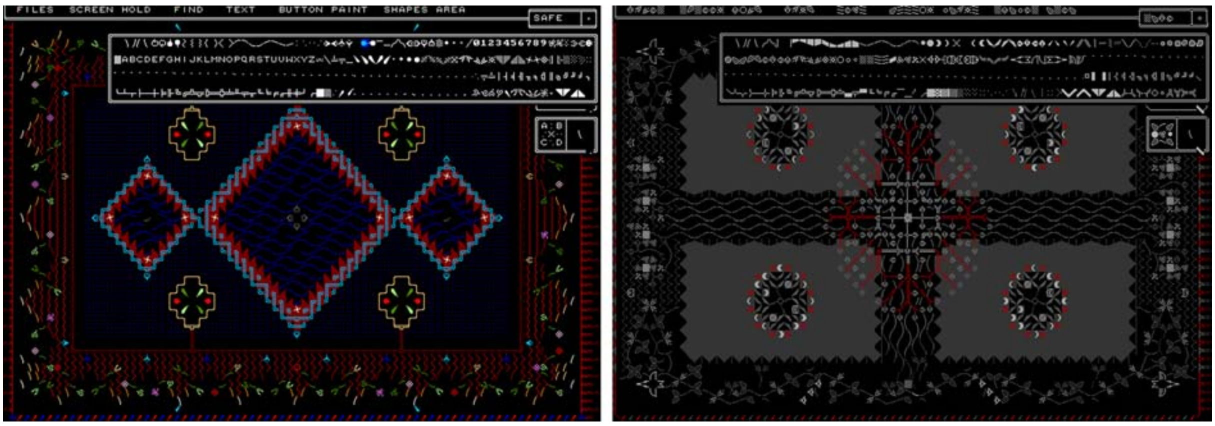

Figure 9. Progressively modified character sets from *Dark Matter* and *Tree of Life*

Figure 10. Progressively modified Vango menus and tools

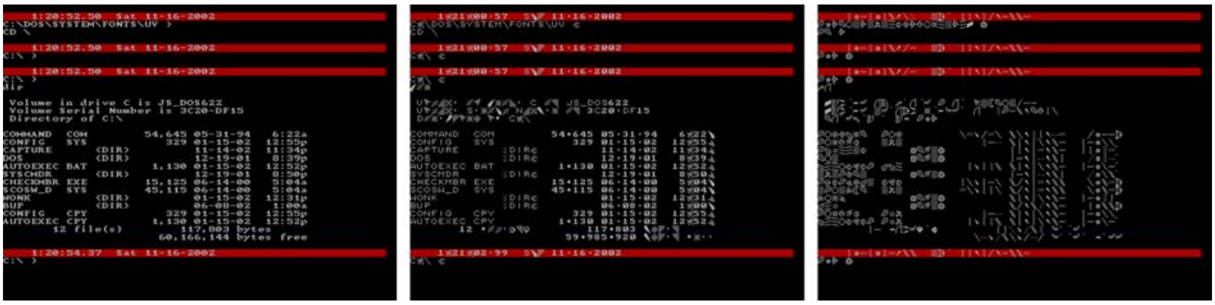

Figure 11. Progressively modified DOS screens

The second problem was that Vango was a unique world unto itself. It was character based, it could only handle pixel graphics in an extremely limited way, it could only generate a few of MIDI events, it could not cooperate with any of the other evolving pixel graphics systems, and its hypertext capabilities were about to be superseded by web tools. Vango had become too isolating and unique, so it was time to move on.

3. *Garden of Initial Conditions* and *Emerging*

Garden of Initial Condition and *Emerging* are two installation artworks I created between 1996 and 2001. As with my earlier work, these works were presented as human-scale, immersive, real-time, computer animated installation performances with accompanying DNA-driven synthesized music[3]. The evolving carpet-like images were projected on a dimensionalizing bed of sand in a totally dark installation space that made the images float dynamically. In addition, viewers were encouraged to play in the sand and become part of the work. The relaxed pace of these works in conjunction with the DNA music and the tactile projection surface gave the works a sensuous yet meditative quality.

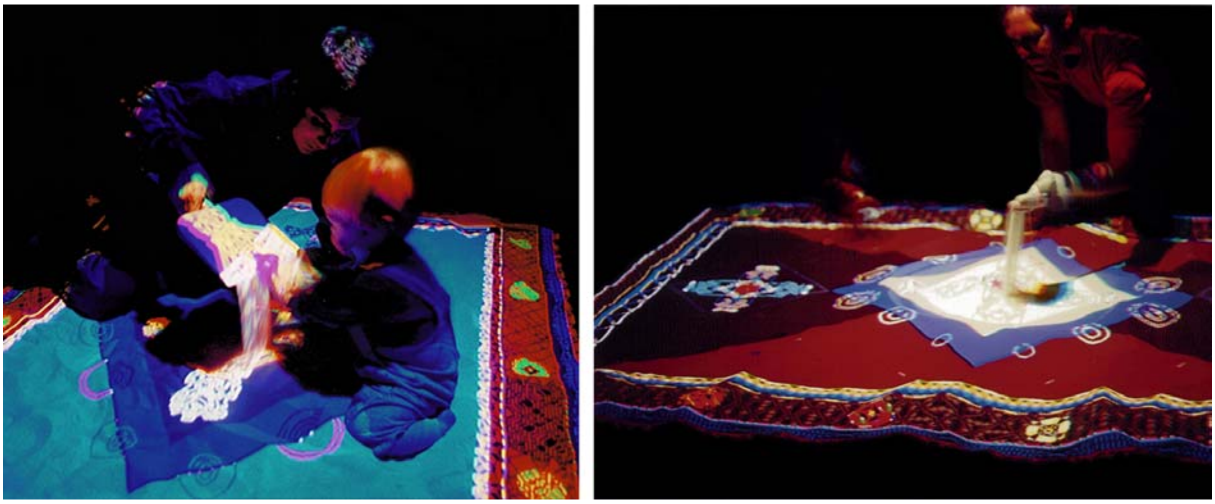

Figure 12. Still images taken from animated *Garden of Initial Conditions* performances

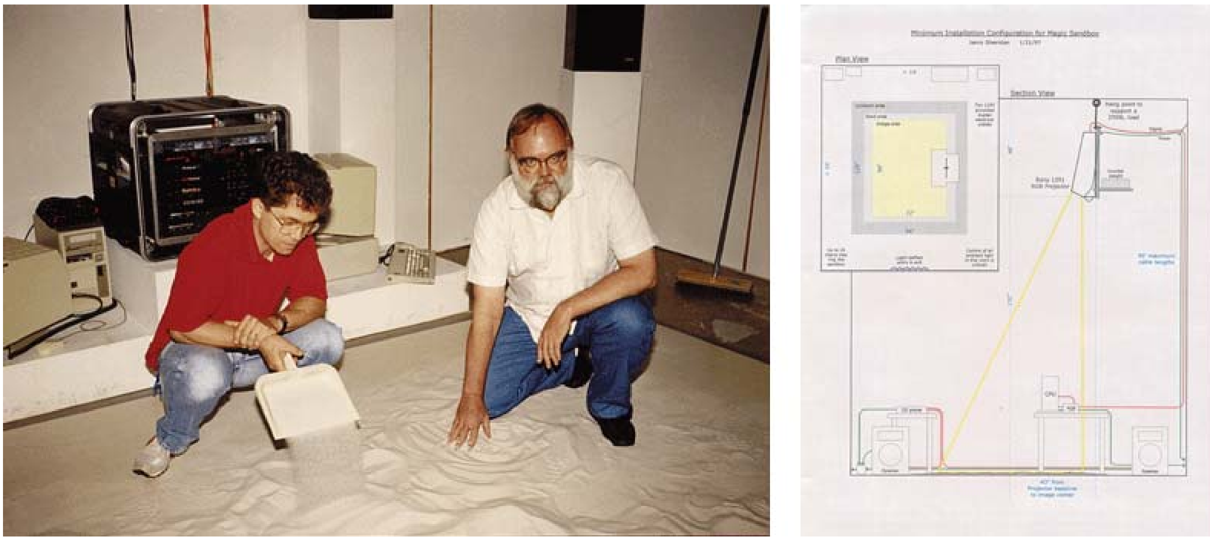

Figure 13. Jamy Sheridan and John Dunn preparing an installation

I created these works using Kinetic Art Machine (KAM), algorithmic multimedia software created by John Dunn in 1995-1996 with my assistance. KAM was a DOS-based software system that grew out of John's earlier Kinetic Music Machine (KMM), a MIDI composition and sequencing system he developed in the mid-1980's that enabled musicians to create sophisticated algorithmic compositions that would run in real-time on an IBM PC. KMM was the system John used to create his early DNA music, it was the system I used to create music for my first Vango works, and it provided a proof-of-concept for many of the ideas that were further developed in KAM. Some elements of KAM also grew out of an ongoing conversation about artists' computer systems and languages that John and I began in the mid-1980's.

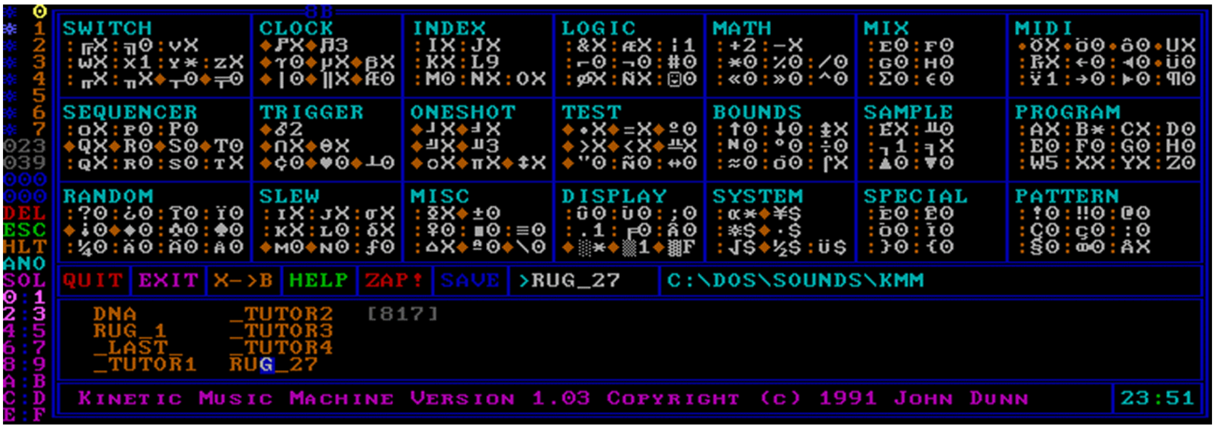

Figure 14. KMM menus

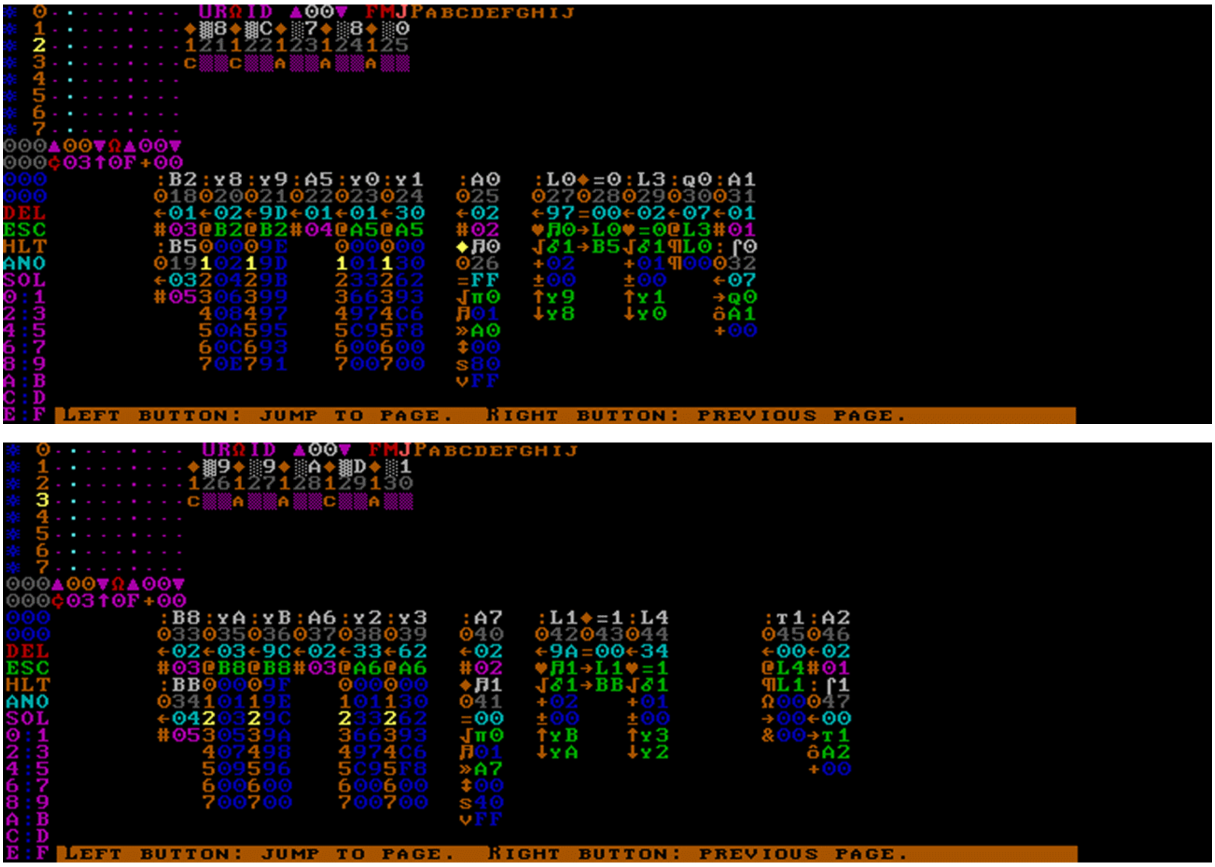

Figure 15. *Rug_27*; KMM code

KAM was conceived as a direct manipulation meta-language optimised for real-time MIDI and data-driven algorithmic visual processes. It was a meta-language in that it was a language to build languages, a general-purpose computer language that enabled artists to build personal languages of form and process. It was a direct manipulation language because KAM only provided functioning modules that the artist programmer could assemble into larger structures using a relatively metaphorless GUI. It was real-time system in that any changes to a KAM program structure or variables instantly affected the acoustical, visual, or functional output of the program. KAM allowed the artist-programmer to work in a very fast, right brain feedback loop and thereby maintain a very direct relationship between the programming ideas and the aesthetic output.

KAM let an artist:

- Create complex real-time program structures that could be used to drive MIDI sound, generative raster graphics, and external processes.
- Explore unusual time structures and relationships by driving individual program processes with independent clocks.
- Save and index into specific states of the system and therefore save and return to various states of the aesthetic process.
- Drive evolving structures, images, sounds, and environments using real-world data, DNA and protein data, for example.
- Connect to the outside world by reading and writing to ports and memory addresses.

As with Vango, after I worked with KAM for a while, I developed a group of generative processes that exploited its capabilities and allowed me to develop unique concepts, mark making processes, and artworks. However, I found three of KAM's abilities particularly important: KAM could use data to drive audiovisual processes, it could embody aesthetic evolution in saved system states, and it allowed me to explore evolutionary concepts such as aesthetic genotype and phenotype.

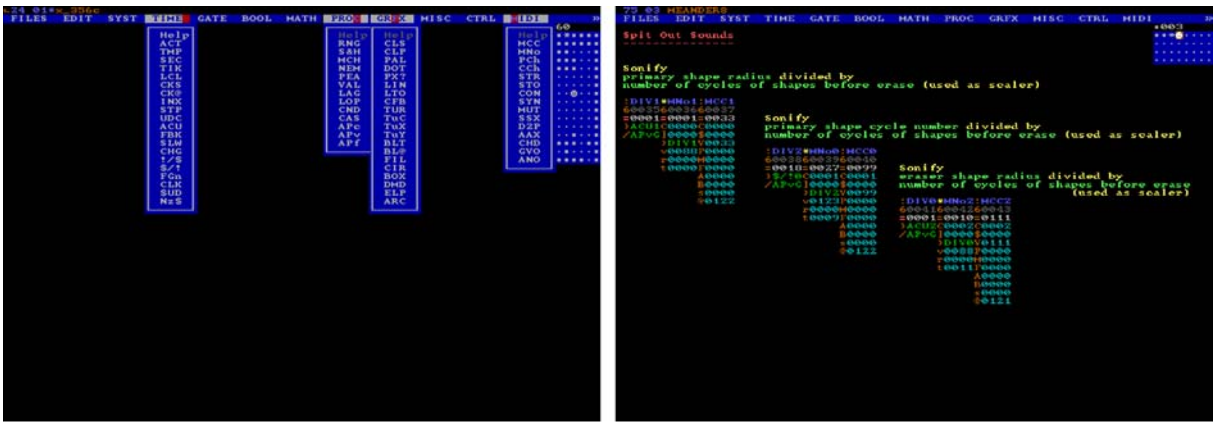

Figure 16. KAM menus and code example

KAM's ability to use DNA and protein data to drive both visual and musical processes was valuable for a number of reasons. First, John and I could use the same DNA-protein data to drive the music and the visuals for an installation. As a result, at a formal level the visual structures I produced with KAM worked very well with the music John composed; the music and images seemed to fit together effortlessly. I speculate that this because we both used the same source data and the same basic generative tools. In addition, using real DNA data allowed me to focus the viewer's mind on the general idea of code driven form and structural cascades; an idea that I believe has many implications in the fields of art, architecture, media production, and social theory to name just a few.

Using DNA data in the artworks also helped convey the idea that the artworks were alive. Physical genetic and cultural memetic processes became equated in the viewer's mind. DNA, at the root of a genetic tree of life, become associated with the 'tree of life' motif, the root of a memetic tree of metaphor. My 'DNA rugs' and the traditional 'tree of life' tribal rugs I referenced in my work were seen as part of the same evolutionary process. Moreover, since the artworks themselves had DNA, viewers thought of them more as living things.

Figure 17. ***Garden of Initial Conditions, strain 1*** **and** ***strain 2*****; KAM code and animation frames**

Conceptual issues aside, on a formal level using the DNA-protein data helped me to create very interesting evolving visual forms. For example, to create the central tree-of-life motifs seen in figure 17 above, I used DNA data to modulate the radii of a series of expanding, contracting and XOR'ing rectangles. The process was like a feedback loop, driven with an apparently random yet structured signal. In any event, by carefully tweaking generative parameters, I was able to get my code to produce some truly wonderful patterns that bore a remarkable resemblance to the familiar yet unique patterns found in best tribal carpets. I used this idea and related non-DNA strategies to produce many wonderful unique generative marks.

I also found KAM's ability to save and index into system states exceptionally useful. In *Garden of Initial Conditions*, I used system states to explore aesthetic genotypes and phenotypes. I created one basic code structure, i.e. genotype. I then copied the genotype, i.e. file, adjusted combinations of parameters such as color, timing, and limit value, then saved the new state of the work. I created multiple strains of the work by applying the selective pressures of my decision making process to copies of the genome; i.e. new files.

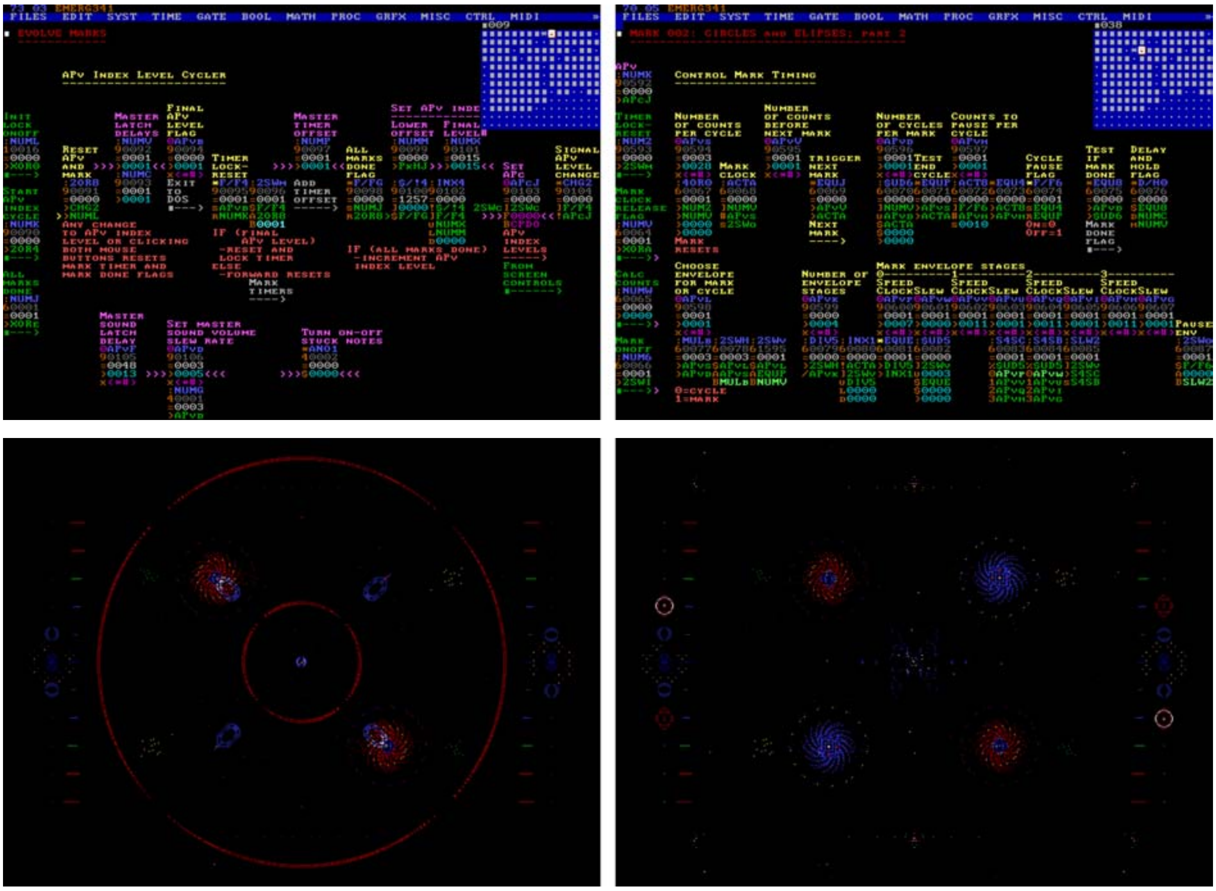

Figure 18. ***Emerging;*** **KAM code and animation frames**

The primary authoring and performance processes underlying *Emerging* were also based on evolving system states, but within a single file. More specifically, I built a simple mark-making engine driven by timed events, then created a series of marks and events which I saved as index level one. I then created another related set of marks and events which I saved as index level two, and so on until the work was 'complete'. This process worked very well, especially given the visual form of *Emerging,* inspired as it was by theories of cosmic and cultural evolution.

KAM certainly was a wonderful tool to use. But not surprisingly, it also presented its share of pitfalls. For example, like all young software, KAM evolved at a furious rate. When John first released a beta of KAM, I built 183 different versions of one piece before we uncovered all the bugs and unintended side effects within the system code and within my own artist's code. Ironically, just as we evolved KAM into being, the DOS world KAM was based on was nearing the end of its life cycle. DOS programs were becoming passé as the new GUI technologies began to dominate.

However, the worst problem associated with the demise of DOS was that, while KAM was a very fast DOS program, fast new graphics libraries and DOS drivers for new graphics cards became increasingly difficult to locate. This meant that John could not easily adapt KAM to take advantage of the ever-increasing speed and accelerated drawing functionality offered by the rapidly evolving graphics hardware systems. This also meant that I could never get my KAM programs to spit pixels fast enough to let my carpets fly in the way that I could with the hardware accelerated, character-based Vango. Another lingering side effect of this shift away from DOS is that I must still maintain seldom-used DOS computer systems just so that I can show my older work, much of which was tuned to a specific CPU.

There was also an architectural constraint built into KAM graphics because of its DOS roots. KAM could only draw on one graphics 'screen'. It was not possible to composite images nor was it possible to buffer images or processing of image components in the background. While a constrained creative system often drives its users to create well crafted and focused work, it also precludes many creative practices. In any case, in spite of our best efforts, the system had again become too isolating and unique. And again, it was time to move on.

4. Sketches for *Life by Analogy*

Fortunately for me, beginning in the late1990's John and I began to discuss how to translate the basic concepts of KAM, as well as portions of its precursors Vango and KMM, into the Windows GUI environment. As a result, and after an enormous amount of translation and new work on John's part, in 1999 he released the first version of SoftStep, a Windows-based, real-time, algorithmic MIDI composition and sequencing system.[4] In retrospect such a move seems obvious, but at the time the speed penalty exacted by the GUI itself was extremely significant. Even with the faster computers, newer graphics libraries, and accelerated graphics cards, it was very difficult to make a Windows system run as fast as the DOS-based KAM system; particularly when you remember that KAM was a real-time system. In fact, at that time it was so difficult to produce acceptable simultaneous real-time MIDI and graphics performance on an affordable PC that SoftStep did not support graphics when released. However, as SoftStep matured, processors, memory and graphics hardware got much faster, as did Windows itself. Accordingly, in 2001 John began to add graphics functions to SoftStep, specifically in the form of graphics libraries accessed through user programmable function modules.

Today, SoftStep provides a relatively metaphor-free direct manipulation GUI environment that enables the artist to do many things including:

- Create complex real-time program structures that can drive and manipulate MIDI sound, generative and sampled raster graphics, text, data, and various external processes.
- Explore unusual time structures and relationships by driving individual program processes with independent clocks.
- Build interactive real-time control surfaces that simplify the process of creating algorithmic music, imagery, and environments.
- Easily program specialized and reusable user function modules.
- Easily create custom scales and other data structures.
- Save snapshots of the system then return to specific states of the aesthetic process.
- Import numeric, text and genetic data sets using the DataBin and BioEditor.

- Communicate with micro-controllers like the Basic Stamp and EZ-IO.

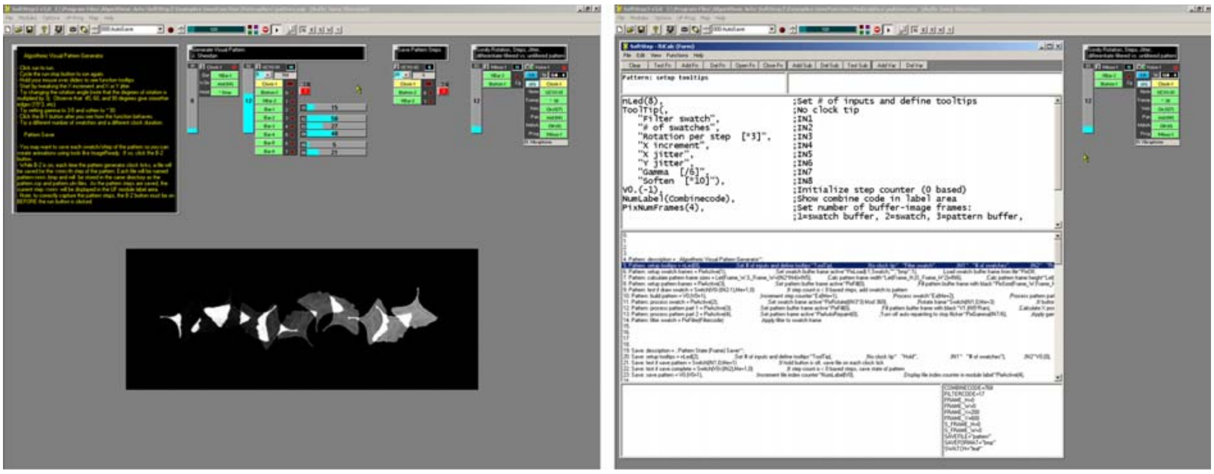

Figure 19. SoftStep code, animation frame and user function code examples

After working with SoftStep since its beta release, I have again developed a new set of generative processes. These processes add to those capabilities that carried over from previous systems such as system state snapshots and data-driven marks. A few of these new processes seem particularly worth noting in this discussion. To begin with, I am now able to use sampled graphics as part of my generative processes. For example, in addition to generating marks from simple patterns of interference or feedback or mathematical equations, I can now create marks by feeding sampled forms and captured picture elements to various convolution, combination and filtering processes. Having this new class of procedural marks greatly extends my expressive palette without requiring me to sacrifice my basic generative approach. I can also mix sampled representational images and generated marks at will, a capability analogous to easily mixing sampled and synthesized sounds. This ability has introduced me to new methods for generating and evolving complex time-based imagery.

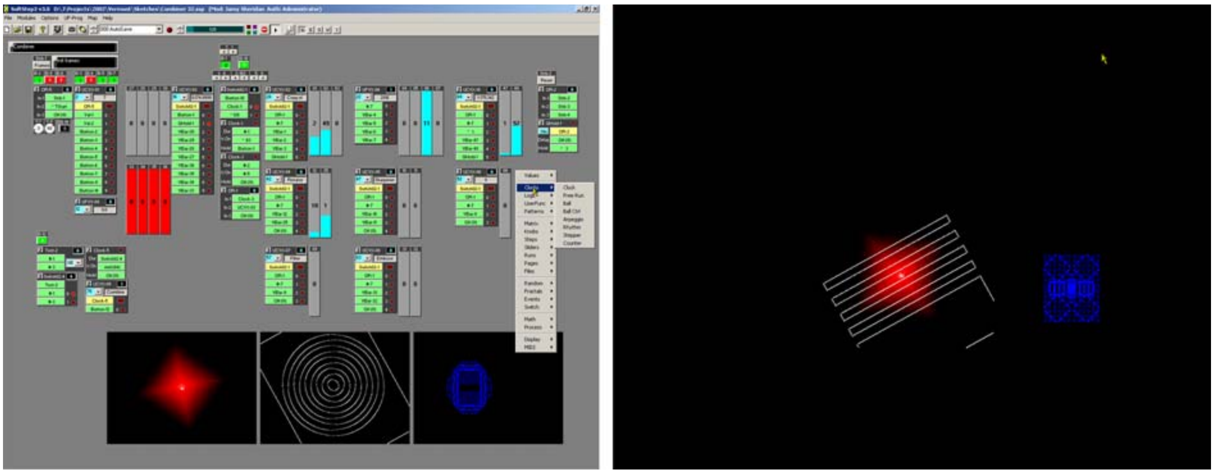

Figure 20. Sketches for *Life by Analogy*; SoftStep code, image components, and animation frame

SoftStep has also made it possible for me to continue and expand my experiments with time-enveloped marks, i.e. marks in which different visual elements or states of an entity are drawn at perceptibly different rates under program control. Time-enveloped marks are analogous to sonic notes that use ADSR envelopes, but visual marks usually run on a much slower time scale. Although I used this enveloping technique extensively when I used KAM, SoftStep's ability to manipulate high resolution sampled images using independent clocks gives me a whole new set of options to explore. I believe that manipulating the envelope structure of generative marks will prove to be a powerful way to develop interesting phenotypic variations or even new strains of an algorithmic artwork.

And finally, SoftStep has helped me to investigate a problem related to envelopes, i.e. how best to produce subtle and expressive generative instruments. A generative instrument is a set of processes and controllers that can be used in real-time to expressively create and modulate generative aesthetic systems. Examples of existing generative 'instruments' include: a brush with canvas, a keyboard with waveform synthesizer, a power carver with wood, a set of Buchla wands with MIDI lights, an Xacto knife with foam core, and a human-scale touch screen with mark synthesizer. However, none of these instruments easily supports the appropriate mixture of computer programming actions, visual imaging actions, sound and event composing actions, and expressive body actions that my working style demands.

SoftStep, on the other hand, begins to allow me to create new instruments by mapping input-process-output relationships in ways that the I/O device manufacturers and software library vendors never intended. I don't have to be a systems programmer to build these connections because John has provided me with an appropriate scale language that makes it relatively easy. I can unite a physical interface to a micro-controller to a generative process running in SoftStep and output the results to audio-video projection systems while simultaneously controlling the installation environment. My instrument may not help me create a true virtual reality, but it will let me create a very expressive and immersive aesthetic experience while running on a PC an individual artist can afford.

Of course, having praised SoftStep's capabilities, it is only right to mention some of its shortcomings, two of which are especially challenging. First, because of various technical problems that arose from building a real-time system in the Windows environment, the graphics functions in SoftStep are not tightly integrated into the modular structure. As a result, I must use multiple programming paradigms to create my work. This makes the learning curve for programming SoftStep visuals much steeper and less intuitive than it could be. But more importantly, this lack of integration makes programming errors much more common and slows down the creative process. Mind you, the create process is still good, just not as good as it could be.

The second, and most serious problem for me with the original SoftStep architecture is the lack of a module encapsulation methodology. On the MIDI side, this problem is not as noticeable because John has already encapsulated so many algorithmic MIDI functions into the existing module structure. However, on the graphics side, while it is quite easy to build a chunk of imaging functionality and wrap it up for future reuse in the form of a user function module, it is basically impossible to encapsulate combinations of modules to make up a 'whole visual function'. This constraint makes it much more difficult to scale up the large mark and image structures associated with a complex artwork.

So, despite SoftStep's power and ease of use, it appears that it will soon be time again to move on to new system, one that has evolved to adapt to the latest needs of generative visual artists and musicians. And, of course, John has already developed the core of a new system designed precisely to meet these needs and more than a few future as-yet-unknown needs. A product of John and my decade-long conversation and John's three decades of programming experience, this new system will return to its KMM-KAM roots by providing visual artists with a very fast, highly scalable, direct manipulation meta-language. However, this language will run in real-time in Windows and be open and extensible, which will make a wide array of platforms, systems and libraries accessible to artists in unique ways.

I especially am excited by the following possibilities. First, I will be able to build very deep reusable hierarchies of marks, forms, and images, any part of which can be programmatically controlled. Second, I will be able to create my own personal appropriate scale language and create extensions to this language. That is, I will be able to build my personal language so that it embodies the level of abstraction that I personally need in order to be able to simultaneously work in the structured world of programming and the expressive world of fine arts imaging. However, I will not have to give up the ability to drill down into lower levels of abstraction when necessary, a sacrifice that many easy to use tools demand. Nor will other artists be forced to adopt my particular functional abstractions, they will be able to build their own. Not only will artists be able to build their own abstractions, they will be able to share and interoperate their functional thoughts with others. Moreover, I should be able to add new low-level functionality as it evolves.

Third, I am overjoyed that I may be able to create computer based generative systems using a language that evolves under me. In practical terms, that means that the system is being designed so that changes to the language interpreter do not require 'rewriting' user level code. This means that I can spend more of my time evolving my artworks and less of my time evolving myself to adapt to the changing systems.

Fourth, I look forward to the possibility that I may easily communicate with laboratory instruments, industrial I/O and control systems, and TCP/IP networks using my own personalized language. This is in addition to the existing MIDI and micro-controller based communications I can use to control lighting, sensing, and environmental systems.

Fifth, I anticipate that I can use the new language to drive other software systems, in essence treating them as specialized function libraries. This would allow me to develop my own non-standard ways to interact with standard systems. For example, 3D imaging, analysis and rapid prototyping systems are particularly suitable for this approach.

Before concluding, I should note here that other comparable languages for artists exist, such as the popular Max/MSP that runs on the Macintosh. However, for me personally, it is the ability to run in real-time on my existing PC's, the ability to interoperate with other PC applications, the ability to participate in the basic design of visual generative systems with John, and the fundamental elegance and openness of the system architecture itself, that keeps me coming back to John's systems to support my personal artistic evolution.

5. Conclusion

For more than a decade I have designed and used computerized algorithmic systems to produce artworks that incorporate generative and evolutionary concepts, forms and processes. When I first began this process, many felt that the major question was whether these generative processes could be used masterfully and whether the products should be recognized as Art.

My experience with the systems described above, and others, has convinced me that the answer to that question is obvious. Given enough time and energy, any process and product can be mastered and can become Art. The corollary is also obvious. Whether or not a creative work or process is recognized as Art at any particular time and place depends on social and historical forces that have little necessary relation to the original creative acts. Artists have no real choice but to just go ahead and explore what seems to them important. In fact, this question proved much too narrow to be helpful.

Instead, I have since found other questions to be more important. For example, I think it is important to ask:

- What types of new ideas can and should artists engage within the creative process and to what extent should these ideas be allowed to transform the creative process?
- What role can the individual human artist play in a cultural economy based upon industrialized generative processes and non-human systems?
- How can artists integrate standardized scientific languages and algorithmic processes into personal visions and expressive languages?
- How can artists capture their personal creative processes and encapsulate these processes in industry standard systems and software; and should they do so?
- How might the generative systems and products created by human and non-human artists function and evolve in the larger social context?

To confront these questions, but not necessarily answer them individually or completely, let me conclude this paper by proposing two conjectures based on my experience with the generative systems I described above.

Conjecture 1. Artists should focus attention on the structure of genetic and memetic systems evolving in time, the purpose being to make the behavior of these systems sensible to themselves and others. By extension, artists should help create and use generative systems that support this artistic focus but that also help existing creative processes adapt to the new circumstances.

I suggest this idea because I assume that human beings have become masters of large-scale industrial production, producing goods, knowledge, life forms, and even new production processes using large-scale social, scientific, and technical systems. I further assume that this productive activity exists in time and has significant impact upon human lives over time. And finally, I assume that some of the new core technologies of this productive onslaught will be genetics and memetics coupled to computer science.

If this is true, I believe it is essential that individual artists produce work by experimenting with simple computerized genetic and memetic systems and other ideas emanating from the world of science. Simple systems let artists see the essence of new forms and dynamics without inhibiting imagination. Sense based systems, ones that incorporate sight, sound, touch, and motion for instance, bring into play the enormous pattern recognition abilities of the human body and stimulate the human imagination. This is important because, as I believe Einstein said, “Imagination is more important than knowledge.”

To support their imaginations, artists should continue to rely in part on the power of a well-tuned intuition. Intuition, or pattern-knowledge, has served many human beings well, including both artists and scientists. However, all creative people should be aware of the limits of validity and functional limitations of any form of knowledge, whether it is subjective or objective, personal or public, intuitive or scientific. I believe it is a lack of clarity on this last point that forces many artists and scientists to misunderstand their own roles and contributions to knowledge and to society.

Artists should also use generative systems that foster experimentation with various time structures because varying the relative timing of the underlying generative processes often produces form variants and varying the timing of sense impressions often changes the meaning or implications of the experience. Stated another way, phenotypic expressions are often time sensitive. These kinds of tools can help artists and viewers develop sophisticated structural and temporal intuitions and surface the new ideas that individuals and societies need to navigate into the future.

Conjecture 2. Since computers capture action in the form of language, a running program and its side effects can be considered the fundamental mark of a computerized generative system.[5] Therefore, artists should work with computer language based creative systems that enable them to directly handle these fundamental marks. Using these systems will also help artists better understand the structure, behavior, and creative potential of reified language, i.e. computer software. However, in the process of working with these systems, artists must also be careful lest their works quickly become extinct due to the rapidly changing computing ecology.

I make this proposal because each creative system is slightly different. Tools are slightly different from languages, clocked events are somewhat different from timelined events, genetic transparency is a little different than optical transparency, and computer marks are different from hand made marks. By implication, the insights each type of system provides and the products it produces are slightly different and effect humans in slightly different ways. Since exploring the subtle differences in life through word, image and music is the traditional purview of the artist, it seems clear to me that artists can naturally adapt to these new generative processes as long as they are empowered to the adjust the processes to their own needs while preserving the essence of the new relationships.

Furthermore, I believe it is very important that artists help explore and articulate these differences between systems. Subtle differences become the small changes that can make the big difference in the long run of cultural evolution. They are the butterflies in the weather pattern of global culture change. It is one of the artist's important social functions to catch, identify, and display these butterflies for all to view.

However, once artists capture the butterfly by creating artworks using the new systems, they should carefully consider how to preserve and share their processes and products. As an artist who has spent countless hours trying to recreate particular computer ecologies so I can show particular works that embody particular sets of non-verbal relationships that cannot be properly communicated in any other way, I can assure you that this is a big issue. There is an enormous difference between the documentation of an idea and the experience of the situation that generated the idea. There is an enormous difference between seeing something fixed into a photograph and seeing the dynamics of that thing. There is an enormous difference between a genotypic abstraction and the phenotypic experience.

If artists actually hope to show their works to future generations, or even a few years from now, they must carefully conserve the entire generative system that they used to produce and show the work. In addition, they must meticulously document the work for themselves so they can remember how the work functioned and what its technical requirement were. Producing the illustrations for this paper forcefully reminding me of this reality.

6. References

[1] CD: *Magic Carpet Music*, 1. for *Tree of Life*: Alpha/Beta/Folding in Proteins, 2. for *Dark Matter*: DNA of HIV #7. by John Dunn

[2] Each ASCII character in a DOS-based PC has three attributes: a character(C) index, a foreground(F) color index, and a background(B) color index. In Vango each character's CFB indexes can be accessed independently.

[3] CD: *Algorithmic Music From DNA*, including HIV DNA #11, HIV DNA #39, HIV DNA #110. by John Dunn

[4] *SoftStep 3.0* by John Dunn. Available from Algorithmic Arts at: http://www.algoart.com

[5] From *Conjectures on Space*, by Jamy Sheridan and Peter Anders, published in *Minds, Machines, and Electronic Culture*, the proceeding of The Seventh Biennial Symposium on Arts and Technology at the Center for Arts and Technology at Connecticut College, New London, CT, March 1999.

A collaborative platform supporting graphic pattern design and reuse of design knowledge

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Abstract

A pattern generation system based on an object-oriented pattern knowledge representation method developed previously in Zhejiang University is introduced. We evaluate the effectiveness of this system from authors' current new research perspective in the Design Technology Research Centre of the Hong Kong Polytechnic University. We then put forward a new platform model to support graphical pattern design emphasising ethnic minority culture. The purpose of building this new platform is to increase the ability of the system in supporting collaborative design. New methods are developed for representing patterns as well as the knowledge about how they can be reused in design applications. In this paper the method for element dynamic classification, knowledge representation of pattern design and the system architecture are introduced.

1. Introduction

In this paper, we will first discuss a pattern generating system using pattern knowledge representation and synthesis reasoning and then evaluate the effectiveness of this system. Then based on the evaluation we will put forward a new platform model called JICPGS (Java-based Integrated Collaborative Pattern Generating System) based on a graphics and image database using a multi-level and dynamic classification method. This new model will improve the original method of pattern of knowledge representation used previously by the authors in Zhejiang University. Through this new platform model, different users at different sites can input patterns into the database, so as to allow designers to use this database later on without having to worry about the management of diversified knowledge and information. We intend to apply this model to pattern design with minority cultural style in China's Yunnan province.

Yunnan has 26 ethnic minority groups. There are a lot of typical patterns with minority styles. These artistic resources have now gaining wide interests nationally and internationally, for they provide inspirations for novel and creative design of textiles and products. But the usage of these materials is still very limited because these resources are still not managed scientifically and systematically. This situation will be greatly improved if a distributed and collaborative platform can be built.

In the second section of this paper, we discuss the mechanism of pattern generating system in our previous research work. In the third section we will analyse the shortcomings of the old system and put forward a new model to solve these problems. In this part, a dynamic interactive multi-level method to manage images and graphical elements according the real needs of designers is introduced. In the fourth section, we discuss the interactive and collaborative design model including collaborative working method and collaborative management. In the fifth section, we discuss an agent based program, which allows the graphical and image database to be extended.

2. Knowledge representation and pattern generation system

Designing a pattern is a process with scarce constraints in pattern layout, colour and element selection. Design rule and experience of designers are often difficult to represent structurally in a computer system. In previous research on computer based intelligent pattern generating system we investigated the issue of how to represent knowledge of pattern and utilise it to generate patterns using synthesis reasoning. The prototype was introduced [1]. In that system, we considered that the there are three basic elements within a pattern:

1. Graphic and image elements adopted in a pattern,
2. Pattern layout, and
3. Pattern background colour style.

We define the knowledge representation of a pattern in the following way:

Layout := <Group> |…| <Abstract Element>
Group :=<Abstract Element>|…| <Abstract Element>
Pattern := <Element> | …| <Element >

An abstract element is an element which has the properties such as position, angle, stretching parameters in the layout definition. A group is a definition that shows the mutual relationship of different abstract elements in the layout definition. A group consists of certain number of abstract elements and all the abstract elements in the same group will select same pattern elements during the stage of pattern generating.

Based on the above definition, here we put forward the definition of a new template. This template is the structural definition of the selection range of an abstract element in the layout definition. A template defines a design problem space within which a layout can be gradually developed into the final design result. A designer can use it to synthetically describe pattern design knowledge. The abstractness it beholds decides that we can use it to generate different patterns with similar styles using synthesis reasoning. The layout definition is more abstract than the template definition. So we have two levels of pattern design knowledge to support different designers who may have different roles in the whole design process. Figure 1 shows the whole process of pattern generation.

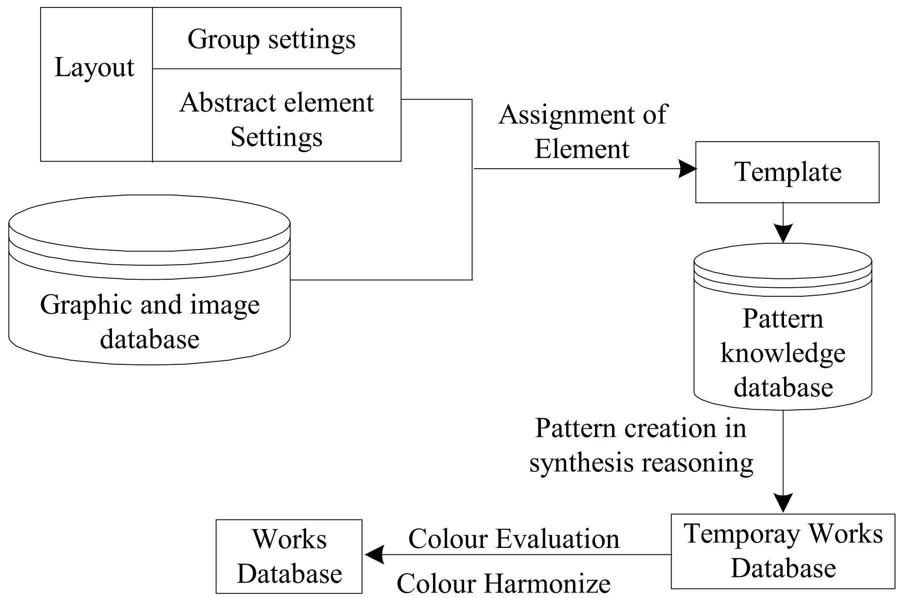

Figure 1: The process of pattern generation

We have used this system to generate images of Dunhuang style, which represents a significant collection of artistic patterns and painting along the ancient silk road.

3. Evaluation of the system developed

Through the long time real use of the system we found that there are three main shortcomings in our system as described in section two. First it is inadequate for complex searching method that designers really need. Second the system cannot handle polymorphism. Third it is difficult to let users share the same resources of the system concurrently. We will discuss the issue of how to solve first problem in section 3.1, the second problem in section 3.2, and the third problem in section 4.

3.1 The Need for a multi-classification method for pattern design knowledge

A pattern has many properties in our database. For example pattern with typical minority style has properties such as dynasty, minority group, usage, colour style, representation method, image quality and patent content and so on. Designers need different kinds of element classification methods to form a classification tree to design his template knowledge when they are facing with different design problems. We need to develop a new method for graphic element classification. This new method uses multi-classification to categorise elements in the database. Thus a designer can perform complex search and select the priority of each classification element to build the classification tree, which is suitable to his/her design project at hands. Here are the details of our classification and searching method:

<Classification set C > =
{(Classification element a),
(Classification element b), … ,
(Classification element n)}

<Searching method> =
<Classification element a> [And |Or] <Classification element b> …
<Classification method> =
<Classification element m> | <Classification element n> | <Classification element o> …

According the classification method discussed above, the sequence of classification element can be selected according the corresponding design task. Thus we can generate different pattern classification trees to suit the needs in different design projects.

All pattern- Classification element m
 |- Classification element n
  |- Classification element o
   |- Classification element p

OR

All pattern- Classification element o
 |- Classification element m
  |- Classification element p
   |- Classification element n

3.2 Polymorphism of pattern and dynamic classification

We also found that designers have different feelings facing with same pattern or pattern element because of their differences in professional knowledge, background and understanding. Here we call this phenomenon as the polymorphism of image and graphics. Our model must have the function for dynamic classification in order to address this issue. The same pattern can be linked to different categories in our database. For example, if we have a pattern, one designer's feeling is that the pattern is a lively pattern of a particular minority group and the other designer's feeling is that the pattern is a decorative pattern of a different minority group, then when we design the database we must anticipate such perception and satisfy the contextual needs of designers. The figure below is a method used in our database design for solving this problem.

Pattern attribute table

Record 1	Attribute 1	Attribute 2	Attribute n	File No
Record 2	…	…	…	

File record table

Record 1	File No	File Content
Record 2	…	…

Figure 2 Realisation of polymorphism

Through this method we can realise the polymorphism of graphics and images in the whole database.

4. Interactive collaborating model for pattern design

A design concept can be well represented with the use of layout and template. But it is still difficult for a designer to finish the whole design process by himself/herself and the mutual communication between designers is not convenient. A more advanced method based on a collaborative environment to allow designers to finish their design tasks collaboratively and effectively is needed [2].

There are two modes of collaborative design. One is asynchronous mode and the other is synchronous mode. In asynchronous mode a participant begins to work after the previous one passed the task to him/her, and only after he/she finishes the work can the later participant begin to work on the task. In synchronous mode all collaborative members work on the same project at the same time, and the modifications edited by each member will be broadcasted to others in real time so that everyone knows what is being modified. Furthermore this mode has two types. One is loosen coupling and the other is close coupling. In loosen coupling mode all the members work independently most time and they share some resources temporarily. In close coupling mode all members share the same views, resources, cursors and files most time [3, 4].

In the process of pattern design, the designers probably have multiple working modes so generally designers will need two modes working together. Here we will mainly discuss synchronous mode and how we realise the interactive design in a close coupling mode [5, 6].

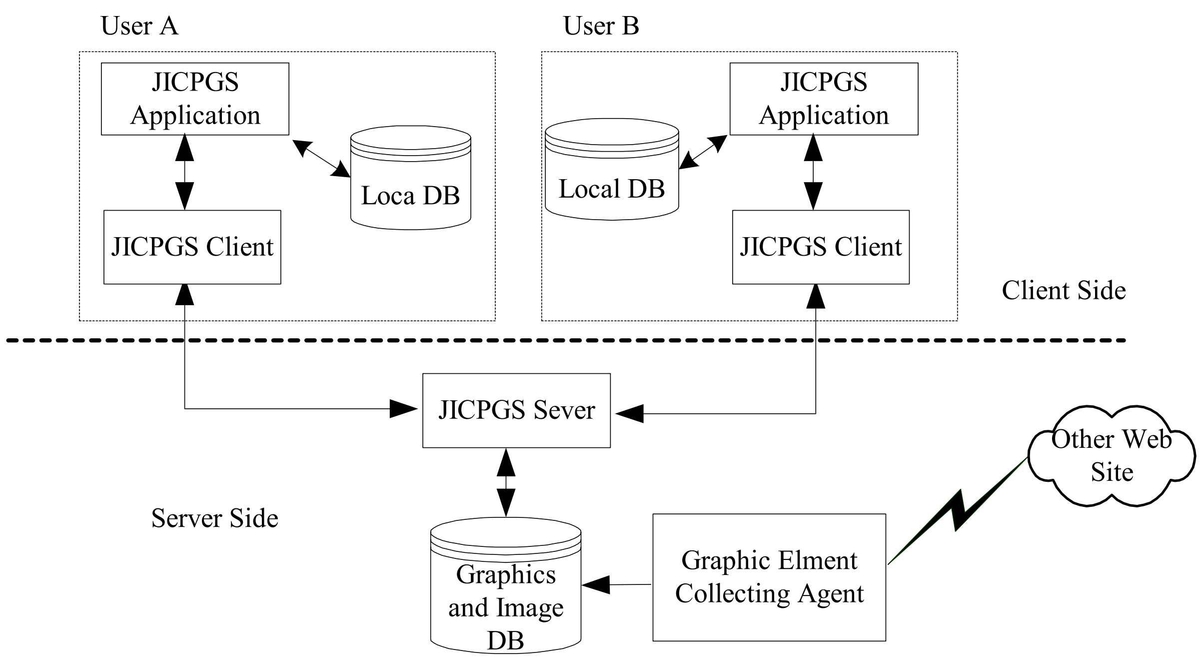

Figure 3: New system architecture

Our platform (JICPGS) includes five main parts: JICPGS applications, JICPGS client, JICPGS sever, database server, and image and graphics collecting agent. Figure 3 shows the system architecture.

4.1 Selection of collaborating mode

Short system response time is an important factor of an interactive system. In our system users can finish the whole design process just using actions such as drag and drop. The architecture of our collaborative system has two main types. One is the central architecture, and the other is the distributed architecture. We adopt the mixed mode of central architecture and distributed architecture to improve the system efficiency.

The realisation of central architecture is easy. But all actions of the members need to be transported to the server and results have to be calculated by the server before they can be displayed on users' screens. As a result, the response time is very long.

In the distributed architecture each member has a copy of the document, and can keep it identical so the response time is short. But it has the disadvantage for data management. When a new member joins the team the new comer has to inform everyone in the team and calculates the current state according the response from other members.

Our system model will adopt mixed modes as we discussed above so we can manage the files and data in both central and distributed manner. Through central and distributed management of files the response time can be cut down to the minimum. It is also easier to maintain the consistency of the files kept by individuals. The system can still work well if one of the member's computers crashes so the stability of the whole environment can be maintained.

In the design process if a user wants to drag or drop a graphic or image element from one place to another the transportation process often costs a lot of time. This kind of transportation occurs throughout the whole design process so the real time performance will be greatly affected by the bandwidth of the network. It is a key problem that how we can reduce the transportation to the minimal extent to improve the system performance. Through the investigation of designers' habits we find that designers often use only a part of large-scale database according to their design tasks. So at certain times only this part of the database is useful to the designer. We can save certain information during the design process to build personal information so the frequently used graphic and image elements can be stored in the user's client side. If the designer needs some more new elements then the system will transport them to the client side. Thus the efficiency can be greatly improved.

4.2 Collaborative management of system

In the collaborative design process the sharing and privacy of information coexist. In the absolute sharing collaborative mode a user can modify nodes without limitations. All members in the team can modify any node (such as group node and abstract element node). But this mode has disadvantage when members are working independently in different extents. A member of a team should have the way to set the permission for visiting, editing, deleting and so on to manage the nodes created by him/her to prevent from any wrong editing [7].

4.3 Concurrent control of collaborative design knowledge tree

We can use the figure below to represent pattern knowledge according our definition.

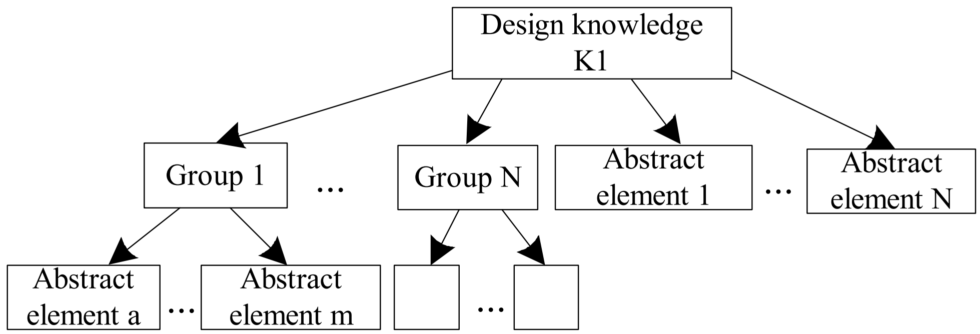

Figure 4: The architecture of design knowledge tree

4.3.1 Locking of directory path

If multi members modify the same node at the same time in our knowledge representation model corruption will occur thus the identity of design knowledge tree is destroyed. We must use concurrent control to avoid this situation.

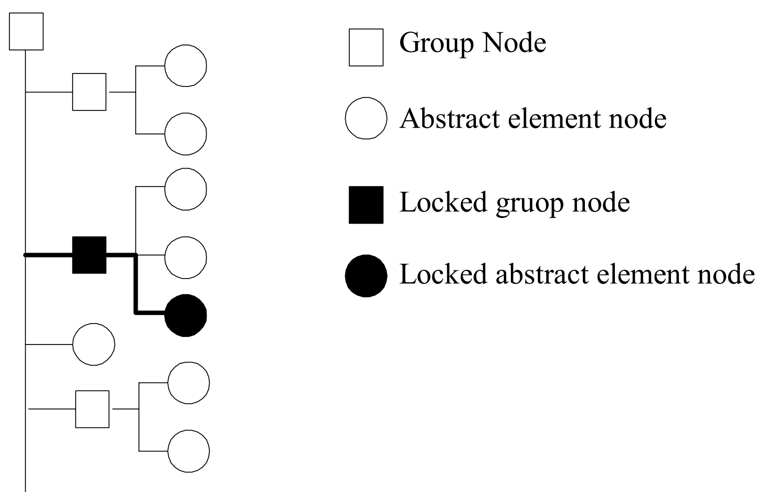

Figure 5: The design knowledge tree with locked directory path

When a member in the team wants to edit an abstract element node he/she has to first get the right that he/she can lock the node to prevent the other members from applying for this node. The other members can only browse this node. To avoid this node becoming an invalid one when other members delete the parent node of this node, the member should trace back to its root node and lock its parent node after getting the editing right of this node. The architecture is shown in Figure 5.

To realise this method effectively, we can set a counter for every group node and abstract element node to show the current state of the nodes. The counter of the abstract element and parent group node is set to false after the application for modifying one node is approved. When the editing procedure is finished these counters are set back to true.

4.3.2 Concurrent control of abstract element nodes

Users will often drag and drop an abstract element to the right position with the right angle, and stretch proportion when he/she wants to add or modify an abstract node. In this period no other user is permitted to modify the node and its parent group node to avoid confusion. The system will lock the node when a user edits the node and unlocks it after the user finishes the editing process.

4.3.3 Concurrent control of group node

There are some basic modification operations for group nodes, such as renaming of a group node, adding an abstract element node into a group node, deleting an abstract element node of a group node, renaming an abstract element node of a group node. Before modifying a node the system will check whether it is locked by other members.

5 Adaptability of element

The aim to research JICPGS is to develop a collaborative design environment within which designers can work together with the support of a large-scale graphic and image database.

To build such an environment a database alone cannot meet designers' needs. The system also needs the function for extending the database automatically so it can learn from the current popular design thinking and the user behaviour.

There are two ways that the system can learn from and improve itself. One way is through the interaction with designers. The other way is through an agent [8]. It is very important to get as many image and graphic elements as possible. With the development of Internet there are many useful resources across the Internet that we don't know. How to use these resources to help designers and integrate them into our platform is a meaningful challenge. Here we will simply introduce an image and graphic element collecting agent. This type of agent can collect elements automatically across Internet. After the collection these elements are not classified and they are simply input into our database without any order. We need another agent that can classify these elements. We will have the evidence when designers use some of the elements to build his design knowledge according certain understanding and usage. So the agent can classify these elements according this information.

6 Conclusions

In this paper we discussed the representation of pattern design knowledge and a collaborative interactive model based on a large-scale image and graphic database. Through this model, multi-level and dynamic classification of pattern elements is supported. The next step of our research is to actually develop ethnic minority pattern design environment through our collaboration with Yunnan Development Centre on the mainland China. In this collaboration, we expect to test our system in close collaboration with designers and artists.

Acknowledgements

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Ecomorphic Dialogues

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Abstract

The biological concept of ecomorphology examines the morphology of the organism in relation to the environment it inhabits. However, the organism itself is an active agent that shapes the environment that in turn shapes it. The two are linked through what autopoietic theory calls structural coupling, and thus the environment itself evolves as an ecomorphic entity. This short paper discusses modelling the process of ecomorphic evolution of an art gallery, which is built around the natural interaction, or hermeneutic dialogue, between people and artworks within it. The natural interactions from the point of view of the person are those based on active perception of the environment, that is, based solely on possiblities that the environment affords to the person. In the model presented here, the possibilities of the gallery are to view the artwork on display, and agents with vision act out the part of the people. However, the artwork itself is engaged in a game in which it tries to place itself in popular rooms within the gallery, moving from location to location to achieve this. Around this visually coupled interaction between viewer and artwork, the walls of the gallery are formed and reformed according to the location of the players, in order to create a constantly evolving space in which the game is played: the ecomorphic dialogue of artwork and art viewer.

1. Introduction

The idea for this short work is taken from a paper by Wheeler entitled "From robots to Rothko" [1]. In his paper, Wheeler develops the notion of a *hermeneutical dialogue* between the viewer of an artwork and the artwork itself, through a rejection of traditional cognitive science, and the introduction of *active perception*. Active perception considers the natural possibilities of the environment as the motivator for action, indeed, for the process of perception as a whole. The possibilities act as affordances, to which the agent within the environment is drawn. If the agent has vision, then the affordances are visual affordances of useful or interesting aspects of the environment, and the process as a whole can be thought of as natural vision. In the words of Gibson: "We look around, walk up to something interesting and move around it so as to see it from all sides, and go from one vista to another. That is natural vision." [2]. Already we can begin to understand why the process of art appreciation might be amenable to analysis by natural vision. In conducting ourselves around an artwork, we do not use a prior cognitive model of where and how the artwork should be, but engage with it directly, in a process of natural vision. Wheeler builds upon recent work in active perception, where the task an agent is involved in, or specifically, the situated interaction, is shown to be the important factor in how an agent interacts with its environment. For example, an agent with wings will fly to a post in the manner of a bee, while an agent with legs will approach the post in the manner of an ant, even if the two are evolved from

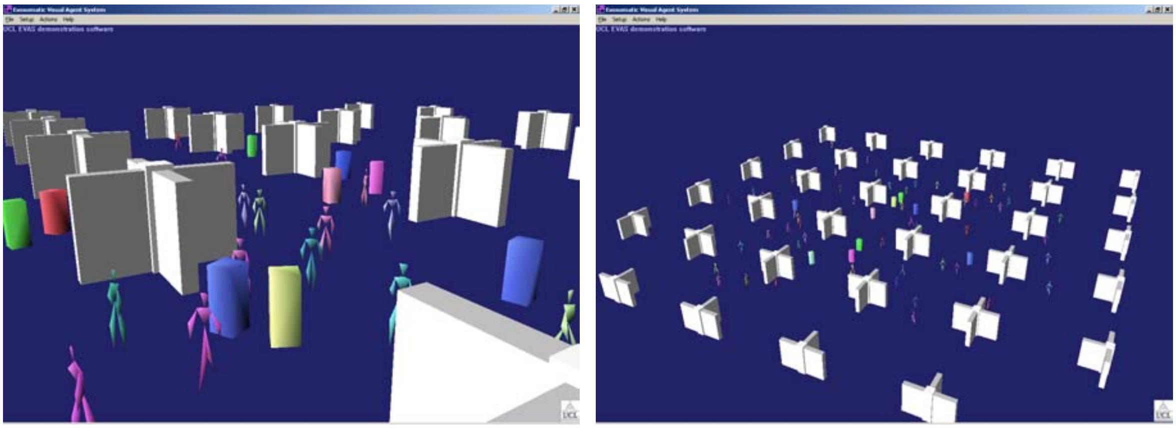

Figure 1: Viewers (people) and artworks (coloured blocks) within a 5 x 5 grid of rooms separated by columns. The colours represent the taste vectors of the agents.

neurologically identical starting points [3]. That is, for the purposes of a discussion about an art gallery, the task of viewing is the essential part of the action of viewing. Wheeler takes the idea a step further to consider what the process is that is occurring between the art viewer and the artwork in during this action of viewing. He argues that both the art viewer and the artwork essentially have an evolved history that comes together in the action of viewing. The exchange that occurs during this action is a hermeneutical dialogue — a natural interaction between art viewer and artwork.

The action we have described is, of course, a private (phenomenological) exchange between viewer and artwork. However, this private exchange occurs in a spatial setting, typically that of an art gallery. This paper aims to look at the spatial consequences of that dialogue, by means of a simple environmentally situated game. Both 'person' and 'art' are considered as actors in the game, in which the person aims to view the art, and the art aims to be viewed by the person. To set this in motion we use agents with vision of the environment who are able to move around artworks, and allow the artwork, also an agent within the system, to move either continuously or occassionally in order to place itself in view of the people. However, as the artwork situates itself the environment is modified around it, so it finds itself against a wall. As the game continues around the two organisms, the environment is coupled to their action, so it itself becomes an actor in the game, forming the possibilities of the art viewers' within the system. The game creates an ecomorphic environment: morphology is evolved around the ecological process occurring within itself: the hermeneutical dialogue between the viewer and art agents in the system.

2. Implementation

In order to realise the system, computational agents with vision are used for both the viewer and art agents. In order to allow a large number of agents with vision, an exosomatic visual architecture is employed [4,5]. This software architecture provides a lookup table to identify visible locations within the environment from any location within the environment. The agents may be released at any location within the environment and progress naturally towards any location within their visual field. This method of movement was shown to reproduce actual levels of movement of real people within an art gallery environment with considerable accuracy [5]. The underlying program we used for these earlier experiments was taken directly as the input for the agents demonstrated herein. The agents take three steps forward before reassessing their goal – any location within their field of view, and then take another

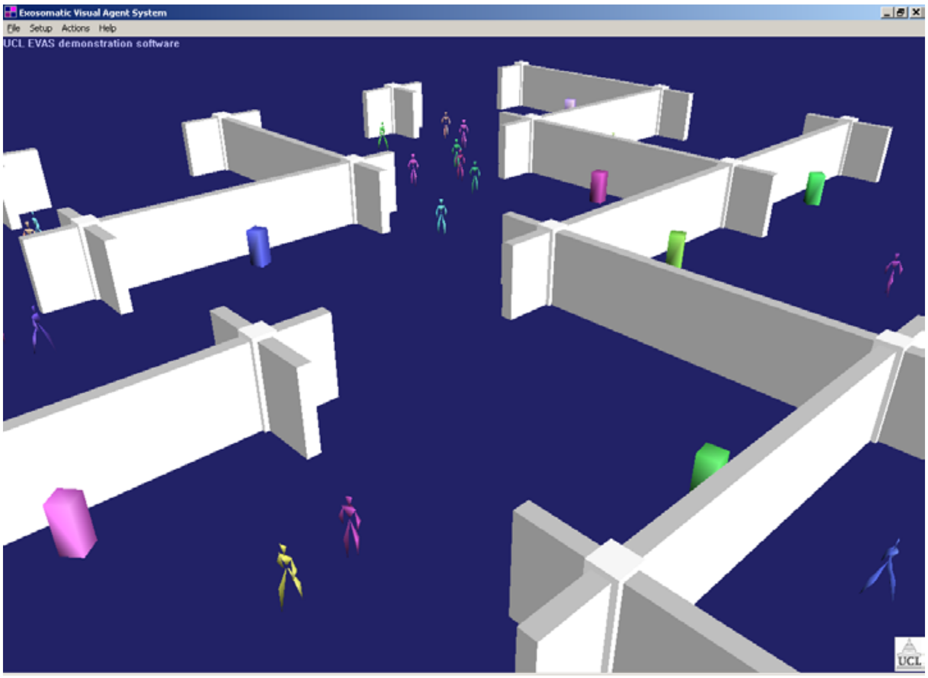

Figure 2: Viewers walk among artworks placed in random rooms. Against each artwork, a wall is formed.

three steps towards this new goal, and so on. As such, this is natural vision within an environment with only configurational interest. For the experiments here, the agents were given desires. The viewer agents like to view art: if they see an artwork within their visual field that appeals to them, they walk towards it and peruse it awhile. Whether or not an agent likes the artwork, and thus approaches it, is based on the relative direction of their *taste vectors,* as introduced by Mottram et al [6]. Taste vectors are two-dimensional vectors that represent likes and dislikes, and vary slowly around a circle as the viewer agent progresses through time, or in response to the artwork that it has seen previously. If the art and viewer taste vectors are aligned, then they appeal to each other, and the viewer walks towards that artwork, and continues to appreciate it until its taste vector moves on. Figure 1 (next page) shows viewers and artworks in a basic configuration, a 5 x 5 grid of rooms separated by columns. In this case, the artworks are either static, or simply move from room to room as they so desire, and the viewers cruise after them until their interest is satiated. The system creates the general action of an ecological game between viewer and artwork, but as it stands, creates no ecomorphic phenomenon.In order to create a morphological response, the artworks are told to stand at distinct places at the edge of each room. As they take their places, a wall is built behind them, so the artwork becomes a feature displayed against a wall. Now the viewer agents are told to move from room to room to peruse the situated artworks, as shown in figure 2. Now the situation is reversed, there is a single morphology and no evolving game between the occupants, other than a pattern of movement generated by the visiting agents.

Therefore, in order to create the morphology around an interaction, the artworks are periodically told to move from their current location and find a new, more popular location. This is achieved by recording the number of visitors to each room over time. After a period, about every 30 seconds, an artwork in the least visited room is chosen to move. As it becomes mobile, the wall behind it is removed and it is allowed to seek out a more popular room. It does this by checking the first three rooms it finds to see if they are more popular than its current room. It then finds a room, and settles in its new location, at the edge of the room, and a wall is once again built behind it, as shown in figure 3.

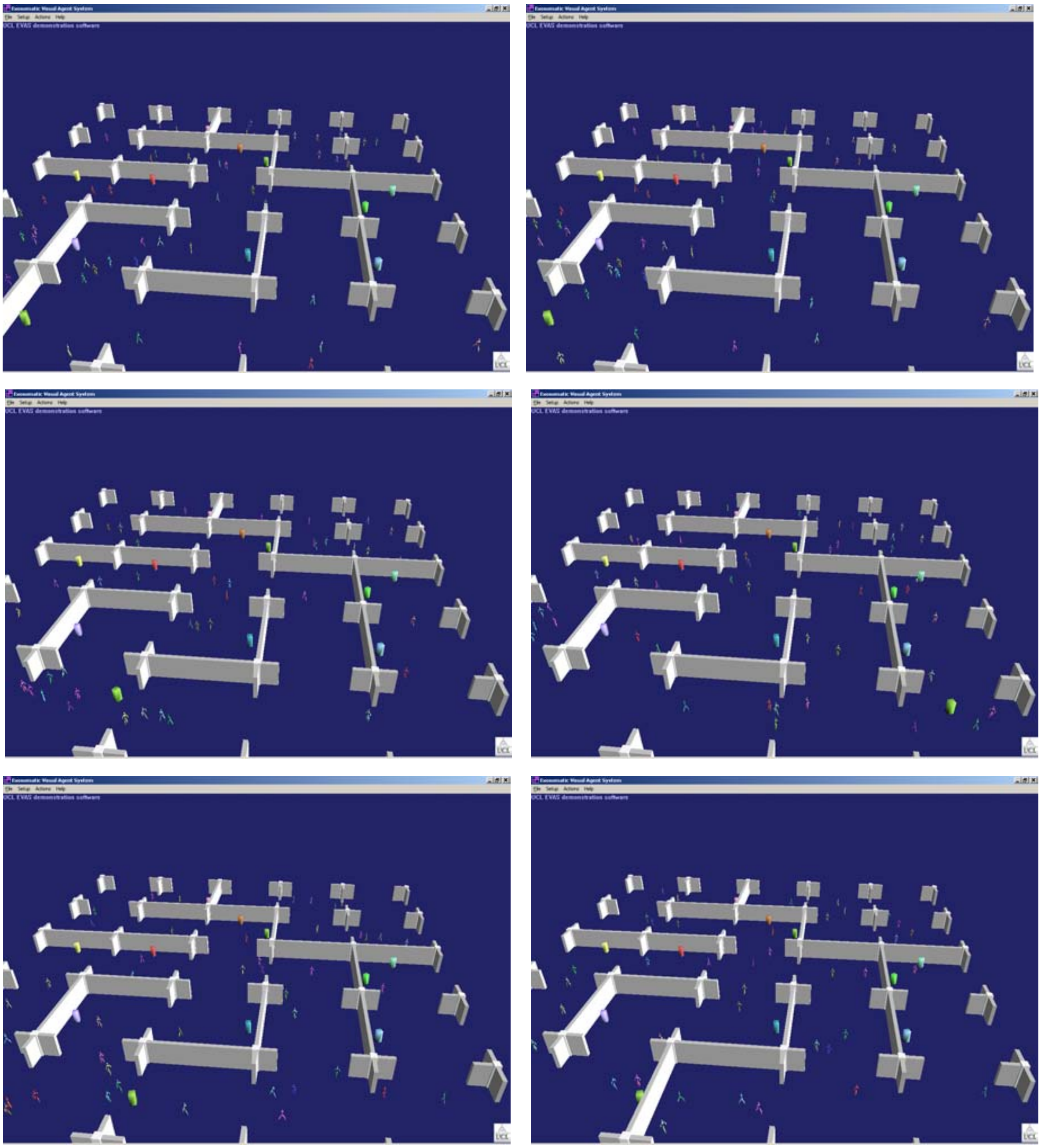

Figure 3: The artwork in the least visited room (the block in the bottom left of the first picture of the series) sets off to find a new, more popular location. It examines 3 rooms before deciding to return to its original room.

The removal of the wall and then its later addition is perhaps a trifle untidy: the reason the program is implemented in this way is entirely down to computational pragmatics. As the exosomatic visual architecture prestores visually accessible locations for rapid lookup for agents, addition or removal of configuration requires significant recalculation. Recalculation is kept to a minimum by removing the wall as the artwork agent begins to move, and then replacing it once again as the artwork comes to its new location, without the wall being in existence for the entire time the artwork agent moves from new to old location.

3. Discussion

The system as described has only recently been implemented. It will be interesting to find out

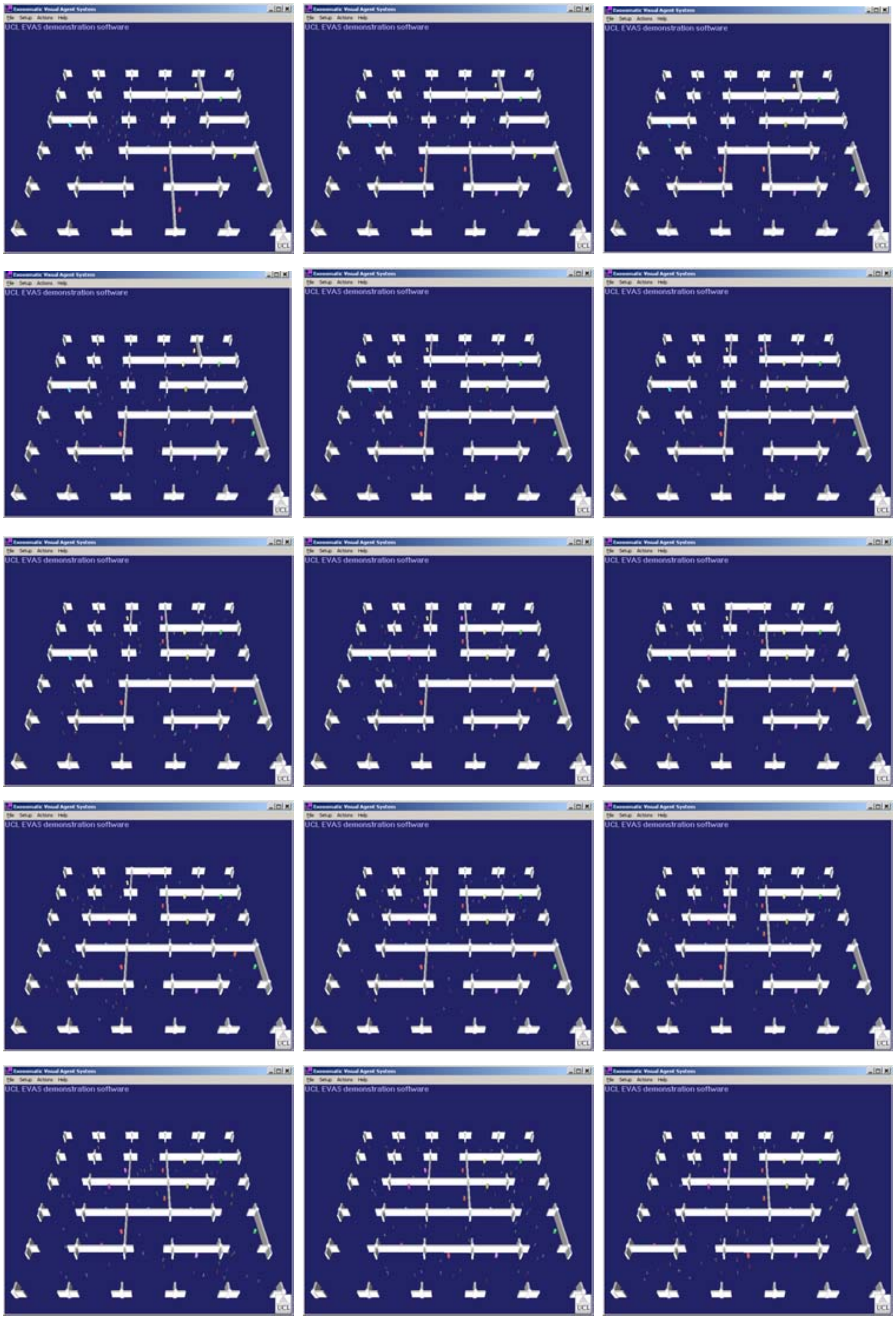

Figure 4: Stepwise wall position changes from initial random artwork positioning to a semblance of order

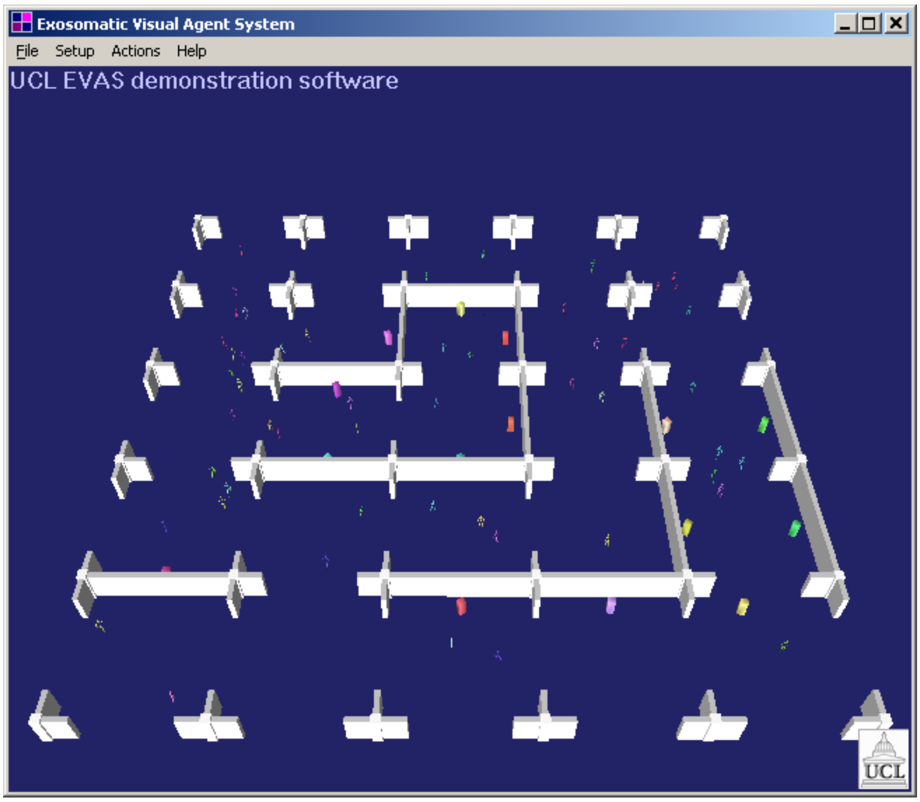

Figure 5: After several minutes more the supposed order of figure 4 has progressed to a different regime: an L-shape pattern of artworks

whether it creates self-organisational ecomorphic environments, or whether the game just plays out to create interesting but essentially random environments. Figure 4 shows a series of pictures taken as the environment develops as walls are removed and replaced. As might be expected, there is a form of emergent system arising: the artworks are slowly centralising, yet forming strict rows for viewing. The final panel, however, shows that all is maybe not as it seems: an artwork disassociates itself from the centralised row and places itself in a prominent viewable position in at the end of an open row. The system is left for a time, and by figure 5 an L-shape of pattern of artwork walls has emerged.

It is too early to tell if the patterns emerging might be the result of some underlying order parameters, or whether the patterns are simply fortuitous. Instead, what has been demonstrated here is an approach which may bear fruit in the future. The system shown here is based on an extremely simple grid structure; however, there is no reason why we might not in the future take down a building from its current format and reapply it to some process to which we might think useful, such as the hermeneutical dialogue between art and viewer in an art gallery, or the process of political debate in a parliamentary chamber. The walls can be reconfigured about the new process to create an ecomorphic environment, structurally coupled to its future task.

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Shared, Collective, Generative, Dynamic Virtual Environments

GENEVE

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Abstract

In this project we plan to create an experimental novel medium setup for the study of the "presence" experience in shared, collective, generative, dynamic virtual environments (GENEVEs) in order to study the cross interactions between a given GENEVE and/among its creators/users and to explore the logic of presence in each GENEVE. The new shareable/generative media will try to add personal creativity and social dimension to telefruition of contents. For the European Industry having a leading edge in the technology for hw/sw/contents for shareable novel media is both a strategic asset and a social imperative.

1. Introduction

The Television industry, besides indisputable "good", has been often criticized of being responsible of many "evil", among them of increasing isolation of citizens in general and divide among family members. The added interaction dimension (i.e. as in videogames) is far from having improved the situation. Movie and theater have been (partially) spared from this criticism mostly because of their "intrinsic" social dimension in the fruition process. The new shareable/generative media will try to make the best of both worlds adding personal creativity and social dimension to telefruition of contents. A European Industry with a leading edge in a technology for hw/sw/contents for shareable novel media is both a strategic asset and a social imperative.

1. Objectives

In order to better understand the objectives of the GENEVE project it can be useful to discuss the space illustrated in Figure 1.

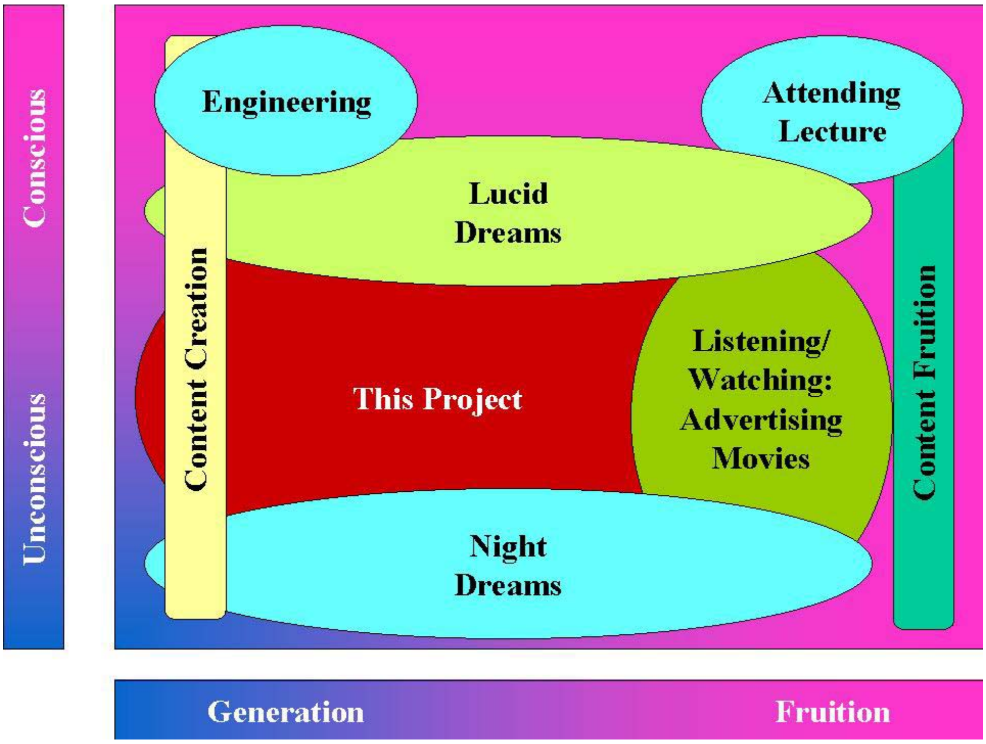

Figure 1: An Abstract Space Illustrating GENEVE concepts

If we partition that space along its two dimensions Unconscious-Conscious and Generation-Fruition we can easily visualize the following facts:

- Usually, in the media industry, including the video/computer game industry, the generation/creation and the fruition of the "contents" are two completely separated processes.

- There is, on the contrary, a continuum ranging from Unconscious to Conscious in both (the separated) situations of generation/creation and fruition

- Night dreams constitutes the best natural examples in which, at an unconscious level, generation is synchronically linked with its relevant fruition.

- Lucid dreams are the dual example of the previous, at an (almost) conscious level. A new research (and industrial) interest is growing about their possible applications.

Those applications relay on the possibilities to “steer” the unconcious natural production of dream content towards some conscious direction.

- There is still a portion of this space to be explored that spans at the (fuzzy) border between Unconscious and Conscious. In this region, generation and fruition can be brought, if not really synchronic as in the case of dreams, asymptotically close. Their distance will diminish with the improvement of the technology. Realizing an artificial real-time 3D environment in which this is possible and study it, are the main objectives of the GENEVE project.

On this basis the GENEVE project has the following objectives:

1. To create an experimental novel medium setup for the study of the presence experience in shared, collective, generative, dynamic virtual environments (GENEVEs).

2. To study the cross interactions between a given GENEVE and/among its creators/users.

3. To explore the logic of presence in each GENEVE .

In order to acheive the previous main project objectives we foresee that:

A) On one hand, the creation of the novel medium setup will require the use and/or integration/development of the following technologies that can be classified as follows:

- Features (advanced existing technology that at the present state of the art make the project research feasible)

- Non standard displays (i.e. all surfaces dynamically steereable projectors)

- Improvements (advanced existing technology to be improved in order to fit project needs)

- Custom Avatars created automatically from people’s bodies

- Generative 3D graphics

- “Genome Database” Sharing among creators/users (GENEVEs are generated using information stored in a “digital Genome”)

B) In turn the novel medium setup will allow to address the following Research Challenges (original contributions to presence theory):

1. Study of Consciousness/Unconsciousness relevant role and logic in mind’s projection through GENEVE based media.

2. Study of Inter-Active-Generative fruition-making in GENEVE based media.

The scope of this research is to contribute to the theory of presence and in particular to the part of it regarding the projection of the mind to designed environments. Since in GENEVEs the environment is only partially and loosely designed beforehand, being for its major part generated real time by the creators/users, we expect to contribute originally to the theory of presence studying it from this particular perspective .

Moreover, while is out of the scope of the present project to make a consistent theory of consciousness (and of its “embarassing” counterpart, the “unconscious”), we will study the projection of the mind from both its conscious and unconscious sides.

The investigation will be carried out using an artificial real-time 3D environment, developped during the first phase of the project, that could constitute the prototype of novel media where fruition of contents will be fading into its own generation.

One of the aims of GENEVE is to try to assess the role of creation vs fruition in determining the quality of the presence experience. After all in real life we are seldom passive, as we are in normal media fruition. Even interaction is a limited activity because is bound to the limits of the environment that has been designed beforehand.

GENEVE will be transdisciplinary bringing together researchers ranging from experts in media psycology to telecommunications belonging to both academia and industry.

State of the Art

1. Underlying Basic Technology (That is: the research is technically feasible.)

All the underlying basic technology involved in this project is present state of the art. In particular:

- Generative Visual Art is now a well established field of research. This field capitalizes on the tremendous advances in both computer graphics and genetic computation.

- Genome Exchange and Sharing has been pioneeed by Steve Grand’s world best selling video game “Creatures” and is now a well established industrial procedure.

Hence the experimentation needs can be initially met by current state of the art technology.

2. Psychology Formal Theory Background (That is: the research is scientifically founded).

If we regard at the story of media we can see a paradox: while the technology has improved, thanks to our increasing knowledge of the conscious part of our perception system, the quality of contents (dramas, movies, musics, etc.) has been linked, in a way or another, to our capacity of addressing its unconcious counterpart.

Failing to take into account the deep unconscious (and not just the "emotional" part of human experience) has created a hiatus between what technology pushes and what mankind demands. By the way cartesian paradigms have been challenged from several parts: [1], [2]

The scientific investigation of the present project will explore especially (albeit, of course, not exclusively) the unconscious dimension of this mind's projection starting from Matte Blanco [3] formal theory of the logic of the unconscious.

In order to carry out our investigation in a sistematic way, a reference, formal, paradigm is necessary. Hopefully we have an exceptionally good fundamental theory to be based on. Ignacio Matte Blanco in his book "The Unconcious as Infinite Sets" [3] formalizes the logic of unconcious. We will try to summarize here his theory in a very coincise way (the book is the collection of a lifelong set of scientific articles in some 500 pages). Matte Blanco formally demonstrates with both empirical and advanced mathematical evidence that the unconscious do have a logic. The apparent "illogicity" of it is due to the fact that we have, insofar, analized the inconscious with an "unsuitable" (formal) logic. Much like Einstein had to abandon Euclidean Geometry for its General Relativity theory [4], Matte Blanco had to abandon Aristotelian Logic. As it was really fortunate that Einstein had new geometries being available at his time. The same happened for Matte Blanco as far as logic is concernd. (Curiously enough one of the advances of Matte Blanco theory requires a 4-dimensional space, the same explored by Einstein [4].) Other contributions to Matte Blanco theory have been derived from Russel's set theory [5].

3. Hot and Cold media. Active vs. Passive fruition

One of the most widespread commonplaces of media fruition is that the perception is a "passive" process. From various parts it has been objected that this is could be far from being completely true [6], [7]. Marshall McLuhan [8] with his distinction between "hot" and "cold" media addresses also this issue. In fact the fruition process may be a very active one. But, still, we are fruitors of contents created by others, albeit we may be active fruitors.

In saying 'the medium is the message' Marshall McLuhan [8] points (among other things) to changes in meaning that occur when using different media. In the context of this project, one can regard the mixed reality environment that is being created as a novel media setting which will also incur such changes.

In this setting, the participant is not merely a spectator but at the same time the (co)creator of the 'space' in which they take part. Moreover, 'creating' in the context of this project does not mean manipulating ready-made, prefabricated objects. All elements surrounding the participant(s) are generative. They grow, evolve and develop following their ‘genetic code’, which forms the basis of their form and behaviour. In addition, the action and inaction of the participant(s) with and within the environment (co-)influences the developmental process of the content making up the environment. Hence, physical meaning is given to ‘space as process’.

It is obvious that by placing higher-level creative capabilities directly into the hands of the ‘experiencer’, this novel media setting shapes a different kind of interaction as well as a different sense of ‘presence’. Separately the technologies used here were probably developed within in a framework and mindset likely to be very different from the setting they are placed in now. This calls for an exploration of possible new methodologies, metaphors and approaches in the research and design of such environments. The organic approach seems suitable to describe the processes with and within the kind of mixed reality environment envisaged.

The organic-ness (cf. organicism, [9]) of the process generating the content extends towards and beyond the interaction, the presence, it engulfs the space(s) it creates and the experience thereof. The use and investigation of the organic metaphor/analogy in a mixed reality setting such as this one, proves relevant because of various conceptual similarities and relationships. They are exemplified in elements such as the questioning of certain (Western) dichotomies such as inside/outside, subject/object, part/whole, the revaluation of a notion of product as a mere snapshot of process, that of intermediary space, of symbiosis [10], etc.

Advances with respect of the present state of the art

“Generative” creation of contents

The Inter-Active generative creation of contents (texts and “scripts, images, musics etc.) per se, as stated in the previous section, is a mature field of investigation and constitutes one of the underlying basic technology on which the present project is founded. It capitalizes on the advances of Artificial Life, Genetic Algorithms, Complexity Theory, Memes Theory, among others.

In this project we want rather to conceive a novel medium setup in which it is possible

1. to generate a real psychological feed-back between the creator and the generatively created content

and

2. to investigate the new presence dimension in which may be living (consciously and) unconsciously the active (real time, Inter-Active) creators/users of (shared, collective, generative, dynamic) contents.

Up to now no attention as been paid to this important aspect. The research has, up to now focused only on the basic technology itself.

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Generative Design:
Rule-Based Reasoning in Design Process

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Alteration, movement without rest,
Flowing through the six empty places,
Rising and sinking without fixed law,
...
It is only change that is at work here.
from "Yi Jing" (Book of Change)

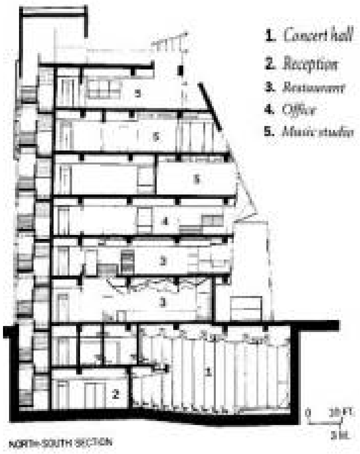
Life is no thing or state of a thing, but a continuous movement of Change.
S. Radhafrishnan

Introduction

As emphasized by Professor Soddu's series of pioneer works on generative design, the fundamental theoretical base can be generally considered as a design process that generates design by the initiation, developing and manipulation with designers' objectives as well as their associated set of rules. This process is, in a broad sense, a reasoning process that follows the rules being set forth. In many cases, the rules are common logic that governs our reasoning, while in others they are more special rules that restrict the generating process to a confined space. Computer assisted generative design has made impressive progress over the past decade, along with the rapid growing capacity and speed of computers as well as development and discovery of rules, rule setting and effective manipulating schemes and algorithms. After many impressive progress and remarkable results has demonstrated from time to time, however, theoretical foundation of such design approach, or the significance of awareness of such approach has not been thoroughly treated, recognized and discussed, not to mention clearly understood.

There are also confusions and misconceptions, or sometimes simply misuse and misinterpretation of technical terminologies, such as "rule-based", "automation" "CAD" … which could refer to very different design and operational schemes in the realms of artificial intelligence or presentation/reproduction tools. The following two examples illustrate some of the differences.

In the first design example (Opus Building, Seoul, Korea) shown in figure below, the angled planes of the building is the result of response to the daylight envelope rule set by the city regulations, while maintaining a goal of making the most use of its limited site space. This is good example of generative design with rule based reasoning process, even though computer technology was not responsible for generating the original design.



Opus Building, Seoul, Korea

In the second example shown in the figure below, computing technology was the vital and enabling element that is responsible for being able to reproduce and represent the original design made with cardboard model into design drawings. Although heavily relying on computing technology and automation, the basic design approach is not the same as that of generative design based on the process of reasoning with rules.

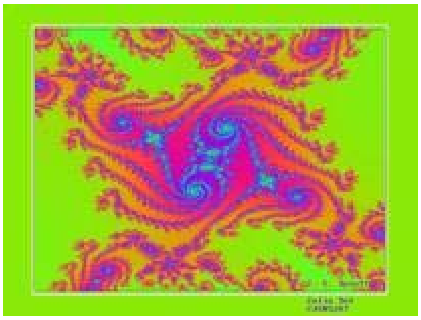
This paper dedicates its focus to the discussion of some fundamental and important issues of the generative design approach and rule based design reasoning.

Generative Design

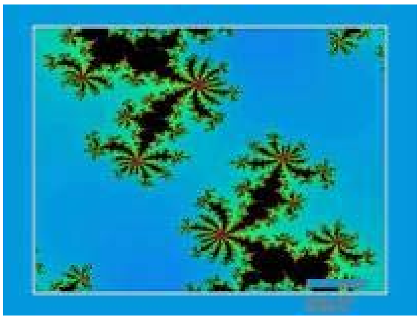
Generative design approach is a design approach that generates design concepts and/or artifacts based on a set of rules governing a process of manipulation of original ideas or requirements to satisfy a set of goals.

Design is an activity with purposes, so is generative design. Although the purposes or goals may change over time during the process, purposes do exist and are to be met or strived to be met. In a similar but different paradigm, generative art using fractal technique is an example where complex images are generated as art forms with computers based on some algorithms. The complexity and some times beauty of the forms generated are truly remarkable, and the algorithms used for the generation are often astonishingly simple.

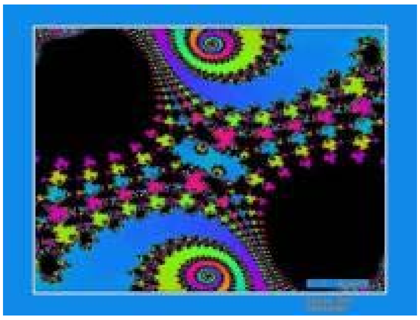
The images shown in the following figure are some example fractals belongs to a class of fractals called standard Julia sets that is generated by an extremely simple function, z^2 + c. They were produced automatically by a computer program that searches the mathematical plane of complex number (as the value for the term c in the function) for interesting cases, where c is given by c = -2 + p / 21845 + i q / 43691 with p and q being two four-digit hexadecimal numbers. The image plots cover the range z = (-0.02, 0.02) + (-0.02, 0.02) i. The seed, or "genetic code" of the seed, that shaped the difference among the images is nothing but the values of the pair of number p and q used in the function. (The values shown with each image are expressed as hexadecimal format.)



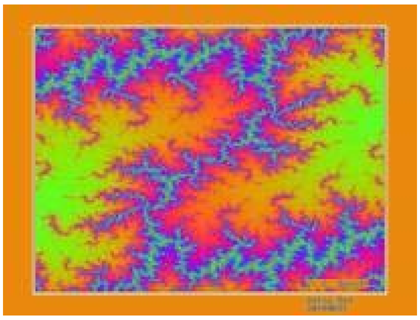
p=c340, q=5247



p=af20, q=6d1a



p=9e42, q=6edc



p=3a54, q=0b31

Issues of Design Reasoning, Processes and Rules

Processing Rules versus Solution Rules

Rules can be recipe like that specifies solution remedies of given situations. Such rules could be called solution rules. There is another type of rules, namely processing rules. These rules do not specify any specific remedies as resolution of specific situations. Instead, they specify the rule of reasoning or processing. In other words, they specify the rules of game. A cooking recipe is a typical example of the solution rules, while the rule of chess game is a typical example of the processing rules.

Expert system paradigm in the real of artificial intelligence is essentially based on a rich set of solution rules, although innovative design is likely to benefit more from processing rules due to the innovative nature of design tasks. The recipe type of solution rules tends to effectively provide known solutions, or in other word, reproduce know solutions when situation repeats. They do tends to be effective and efficient when it come to using known solution to address know situations based on experiences.

On the contrary, the fractal image example is an extreme example of using processing rule. In fact, it is so extreme that the relationship between the rule and the solutions is so remote and unpredictable, which is very much responsible for the surprising factor or "innovation" in the solution.

Less extremely, the Opus building design example presented previously is probably a more typical example of using processing rules. Although the daylight envelope rule does not specify any particular design remedy, it does have clear restricting effect on the design solution. However, such restriction by no means dictates a know solution or limits innovation in the solution, it rather channels the search for solutions towards certain directions that leads to feasible solutions.

Crisp, Vague and Fuzzy Rules

Rules can be crisply clear and definitive such as mathematical algorithms. Rules can also be vague such as certain laws and regulations are some times subject to interpretations. Another type of rules is fuzzy rule. The theory of fuzzy reasoning and fuzzy logic based evaluation belong to this category.

Design as a Wicked Problem

Although rule based processing rules are extremely useful in design reasoning process, one must not forget that design problems are wicked problems. The choice or decision about the solution is subjective by nature and there is no absolutely objective criterion, although objective measures can be utilized to assist the evaluation process.

The nature of design, as a wicked problem, determines that it does not have an objectively persistent goal. Although the design process is a reasoning process of searching for solutions to meet given goals, the goals are evolving as the solutions are. It is not uncommon for designers to find themselves in a situation of a negotiation between goals and solutions and making changes to each site in order to meet the other.

Due to such wicked nature, a design process does not have an objective criterion for ending. The decision of ending the process is more of a subjective matter than objective, since the process of mutual evolving and mutual matching between the solution and the goal can continue forever in theory. In practice, a design process has to be completed within a reasonable amount of time and a solution, as well as the corresponding goal met, be adopted as final result. Although objective measures and criteria are often used as an excuse for the way out to conclude a design process, the decision is ultimately subjective and in a sense arbitrary.

Eastern Dialectics

Yi-Jing: Rules of Change

The oriental philosophy of change and its deep-rooted idea of dialectics is another interesting type of rules that can be very powerful in design reasoning and processes. Since three thousand years ago when YiJing[1] (易经，also known as Book of Change) was written, Chinese scholars (and designers of all sorts) have understood and emphasized the importance of the continuous movement of change rather than the accumulation of artifacts or products.

Seemingly casual, circumstantial, episodical and even sporadic cognitive processes of design reasoning could become quite systematic and methodical in the realm of eastern dialectic. The Chinese theory of FengShui(风水), a methodology applied to site planning, architectural design, landscape design and interior design, is a good example which in fact was originally derived from the theory of YiJing. Another good example is the methodology of diagnostics and prescription in Chinese medicine. The key essence of it is referred to by a Chinese word “BinZheng” (辨证) which means dialectics and happens to be pronounced the same as the Chinese word for diagnostics (辨症). The theory of such ancient eastern dialectics has been studied, interpreted and developed by many modern scholars. The theory of Contradictions and Balances is one of the mainstream interpretation and development of such theory.

Contradictions and Balances

The theory of contradiction and balance is also called the law of contradiction or the law of the unity of opposites. A contradiction is defined as two opposite aspects coexist in a thing as a unity. According to the theory, contradiction is universal that it exists in all things. The theory also states that contradiction is particular that every thing has its particular contradictions. It is the difference of such contradictions determines the difference of the nature of different things. The theory further states that in every thing there is a principal contradiction that is dominant, and that in every contradiction there is a principal aspect that is dominant. The dynamic change and movement of any thing can be explained as the change and movement of the contradictions in the thing, which are driven and governed by three dynamic changes: the transformation of principal contradiction and secondary contradictions, the transformation of the principal aspect and the secondary aspect, and the affection of contradictions on each other’s transformation.

The theory also teaches that the process of problem resolution is the process of contradiction resolution. The best approach of such contradiction resolution is: first identify the principal contradiction and the principal aspect of the principal contradiction, and then to resolve the principal contradiction by causing the principal and secondary aspects of it to transform to the desired direction. Once the principal contradiction is resolved, the situation will change with one of the secondary contradiction rise to become the principal contradiction. The continuously iterative application of above describe procedures will result in resolving contradictions one after another and thus causing the situation (the thing) to continuously transform to the desired direction.

The Process of Design Reasoning seen through Eastern Dialectics

Design process is a process of dynamic movement and change or transformation of design concept or

artifact. All design issues are contradictions exist in the design.
To improve the design (or make it work) is to address the issues, or to resolve the contradictions by causing contradictions to transform towards the desired directions. Addressing a predominant issue is to resolve the principal contradiction.

Design process studies have found that design processes progress in identifiable episodes. In the view of eastern dialectics, an episode is characterized by the state of contradictions. In other words, the resolution, or transformation between the principal aspect and secondary aspect, of the principal contradiction of the design at the time determines the transition from one episode to another. During this transition, the previously identified principal contradiction transforms into a secondary contradictions while another secondary contradiction is identified as risen to become principal contradiction. The subsequent episode would be the process of resolving the new principal contradiction or addressing the new predominant major issue.

The most effective approach of design process is to address the predominant issue first. In other words, grasp the principal contradiction and focus on resolving the principal contradiction first. Then derive a solution to influence and cause the principal contradiction to transform towards the desired direction, or resolve the dominant issue to achieve a more satisfactory state such that the issue is no more predominant concern in the design. The success of such resolution terminates an episode of the design, and the next episode of the design begins with identifying the next principal contradiction, or the new predominant issue.

Within the eastern dialectics framework, the wicked problem characteristics of the design can also be interpreted as such that:

- Contradiction always exists and cannot be eliminated. Resolving a contradiction is to find a way to cause it to transform and reach a new more desirable balance.
- A design concept or artifact as a temporal state during an evolving process is a temporal state of particular balances of contradictions. It is the result of a change (resolving and transforming of contradictions) as well as the starting point of a new change
- A design process has no natural end. The end of each episode of design process is a temporal state in a flowing river of events of changes. The “final” design is only a designer’s subjective choice of a snapshot of the flowing river of changes.

Viewing the design process through eastern dialectics as briefly describe above agrees very well with observations established in modern design studies that focused on various aspects of design such as process, cognition and reasoning, etc. The benefit of eastern dialectic view is that it offers a more systematic framework for analyzing design process and reasoning as well as a pragmatic guideline in practices.

Pragmatically, perhaps some useful guiding principals can be derived from the eastern dialectics view of design as following:

- Design is a series of episodes of evaluation and composition.
  - The evaluation phase of an episode needs to not only evaluate whether design can be stopped as satisfactory but also identify the dominant issue as the objective for the next episode to resolve
  - The composition phase of an episode needs to concentrate on resolving the dominant issue(s) identified in the previous evaluation phase

- Skills for effective design reasoning has multiple aspects
    - The “science”:
        - scientific and technical knowledge and innovation
    - The “art”:
        - Knowing the dominant issues at different stage
        - Knowing the proper balance of the contradictions
        - Knowing the effect of changing balance of one issue to other issues

Examples of Generative Design

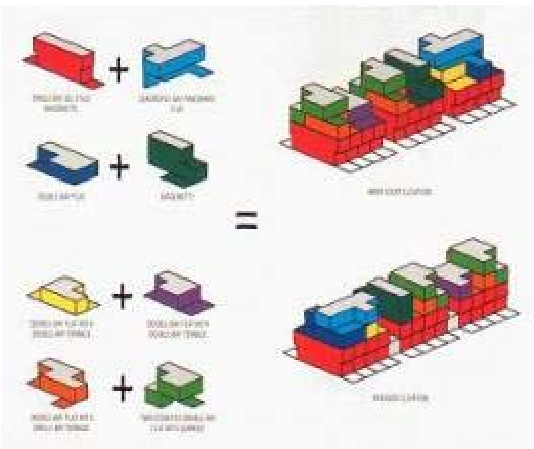
A Student Project

A student in the generative design class (Spring, 2002, Polytechnic Institute of Milan) once showed me her project in which she has created a design and the retroactively defined a set of rules that would lead to the design. With my strong encouragement, she reworked on her design by following the rules that she has defined, she came up with two more somewhat different designs. However, when she gave the set of rules to her sister as an experiment, her sister came up with a very different design by following the rules. To her astonishment, she likes her sister’s design better than her own. This seemingly trivial incident is in fact a powerful example that illustrates the capacity of innovation within the generative design approach based on reasoning rules.

A Modular Housing Design

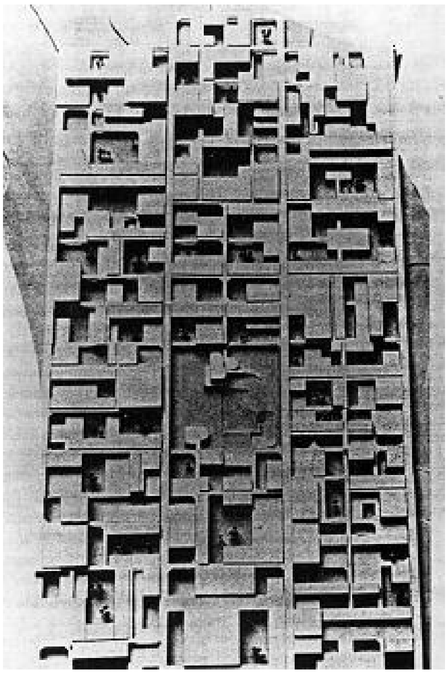
This example illustrates a quite old concept and practice of rule based design. Yet it is a typical and simple generative design approach. The overall design is to be accomplished by composition of a set of subcomponent modules. Restriction rules are defined to insure validity of compositions while allowing rich enough variations for different purposes such as performance optimization and innovative alternatives.

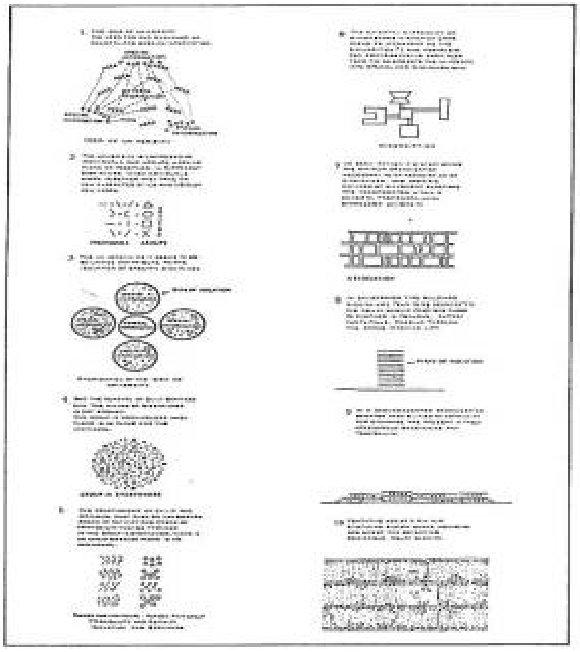
There is no fundamental difference in theory whether the composition is performed manually (with drawing board or scale model) or by computers with special modeling, although the efficiency and productivity difference can be crucial in practice.



An Campus Complex Plan

In this example of rule based design as generative design approach, the rules are significantly more complex than the previous example. However, the fundamental ideas and the essence of the processes are the same.

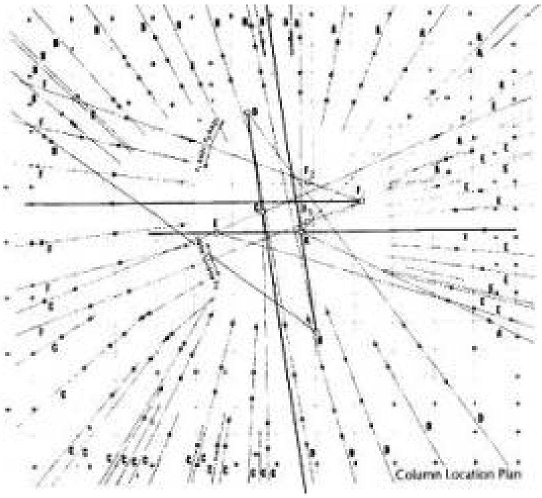


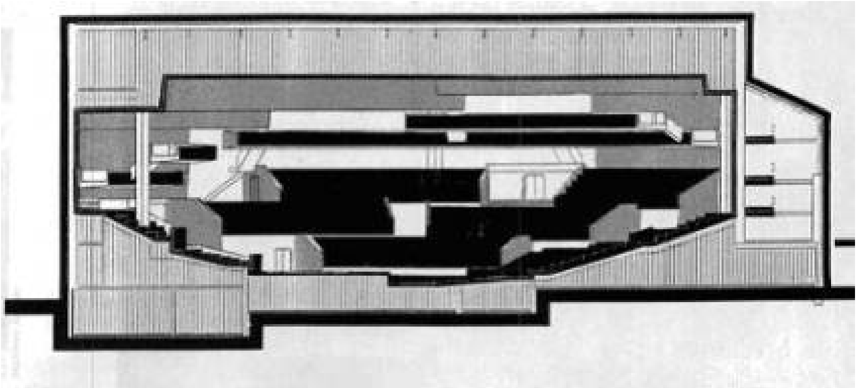


A Concert Hall Design

The following figures illustrate the design of a Concert Hall, Denver Center for Performing Arts, that was build in 1980. (Architect: HHPA, Acoustics: C. Jaffe).

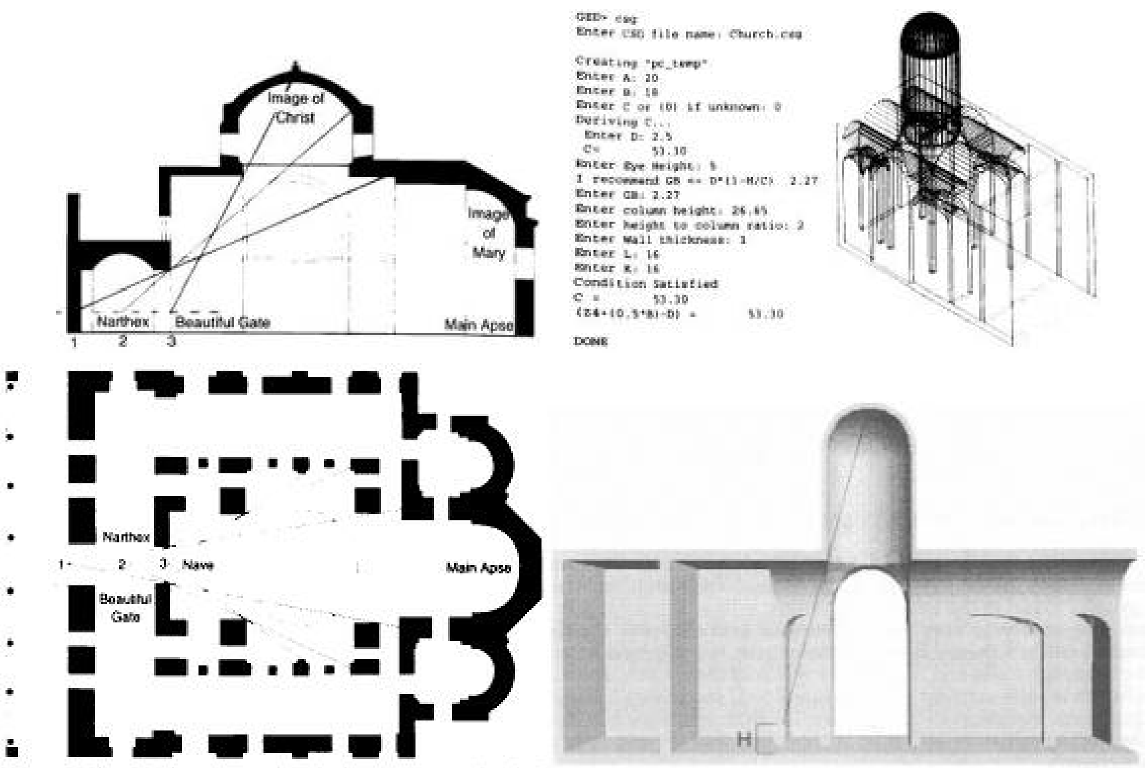
For acoustic performance requirement of avoiding any specific resonant frequency that would negatively affect acoustic fidelity, it is desire that the columns in the concert hall be positioned randomly. The more random, the merrier. However, the design and construction practices dictates that the position of every column can be easily located both in drawings and on the construction site. Such pragmatic restrictions require a simple positioning scheme be devised to locate the columns. In this case, the architect and acoustic designer have worked out a simple geometric rule system, as shown in the drawing below, such that the locations of columns can be easily pin pointed both in the drawings and on site. The rules are simply specified with lines of sight, angles between the lines and distances measured along the lines. Simple and regular as the rules are, the resulted distribution of column positions is remarkably random (considered nearly infinitely complex).


Column Location Plan

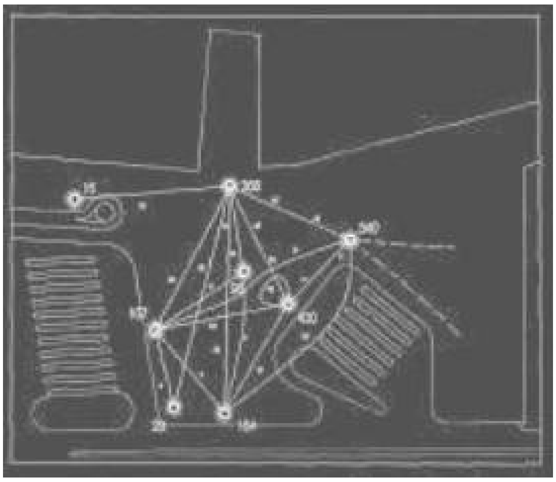


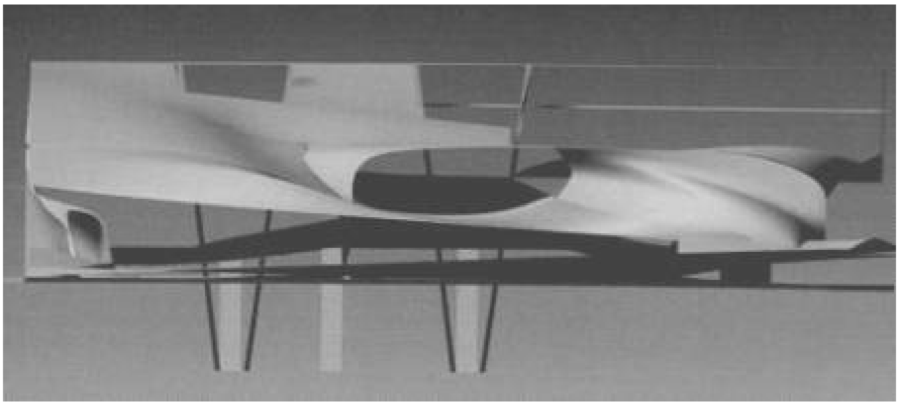
A Byzantine Church Design

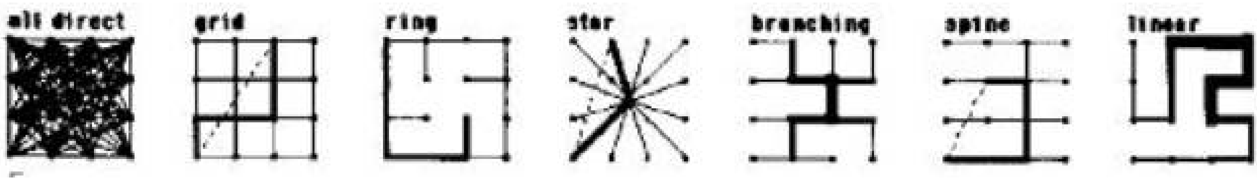
Byzantine church, lines of sight. (Kalligas, 1948) and a church generated by computer with parametric rules. (Potamianos, *et al*. 1995).

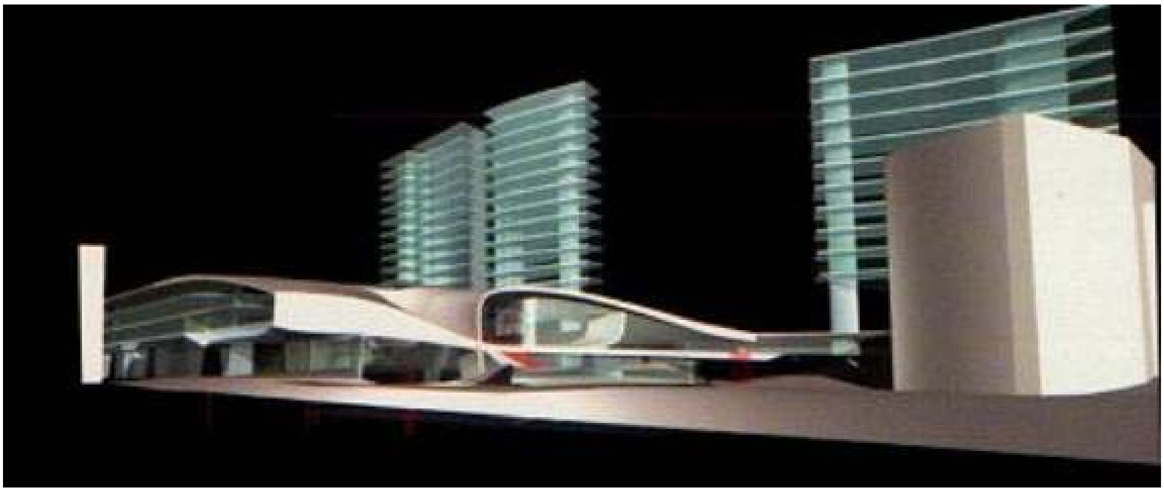


A Train Station Design



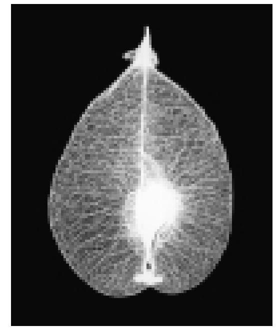






[1] Yi Jing has been translated into English as I-Ching.

In/Visible Cosmos



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Abstract

Visual patterns are central to the organization of life. There is an affinity among these patterns that captures my artistic imagination. The photogram process (*light-drawing*) often *reveals* the underlying patterns where form and formless matter, in either organic or inorganic objects, can be seen in relationship to one another. These relationships are found in photography's alchemical properties from which a visual/verbal language of *light-writing* emerges.

Photography: A Language of Relationships

Being playful with photography's alchemical properties and terms, in relation to language, is my starting point. This form of inquiry provides living and philosophical connections between two counterpoints: phenomena and embodied thought. It allows an intuitive point of view to emerge from an intertwining, sensory experience of the materials and methodologies employed.

To locate what one might call the "essential qualities" of objects, I have begun with an effort to make visible the quality of *self-illumination*. Since all material parts, through the agency of light, have the potential to be visually described, I add or subtract light as a way of locating where layers of an object are transparent or remain opaque in the exposure and development process. These latent shadow details depend largely upon technical attention to particles. The interpretation, elicited by the density of the object's negative and positive layers, impresses metaphorical and poetic thought. These picture words describe how the newly found image relates to structures we remember and associate with other objects.

Transcribed by Sunlight

In sunlight, iron and silver salts convert from a ferr*ic* to ferr*ous* state and, depending on length of exposure and opacity of the object, their values move from light to dark. If the process of exposure is stopped at regular intervals, a scale of graduated

Figure 1

light can be measured, showing a progression of values. When an object is placed in range or direct contact with light sensitive film or paper, layers of the object present themselves as clear, opaque or somewhere in between.

The process of proofing these in-between layers allows me to uncover and make visible characteristic patterns of a form's structure. Light is the crucible where tone and texture renders extreme blacks and whites, as well as a range of greys. If the balance between exposure time and the sensitivity of the salts is lost, what was visible information will begin to reverse and darken. The inherent resist, between levels of opacity and transparency in the object, loses ground to the force of accumulated light (over-exposure).

The surface of the paper fibers receiving and recording the image also influences how lines, textures and translucency read visually. For example, Gampi paper (*washi* from the inner most bast fibers of the Gampi tree), was used for the skeletal leaves because of its beautiful lustre. While the pearl gloss finish resembles the surface of albumen prints and large glass plate negatives of the 19th Century, its tissue weight resembles the weight of a leaf. Gampi, though delicate in weight, has great hydration strength, easily sustaining the several baths required to clear unexposed areas of these Vandyke brown silver–sun prints. (figure 1)

Figure 2

Collecting impressions and comparing morphological generations of my subjects has led me over time to more complex temporal/spatial fields. Sometimes my process of exploration unveils both earthly and metaphysical realms as one unit. What became intriguing in the *Empty Bottle Series* was the emergence of organic patterns contained in man-

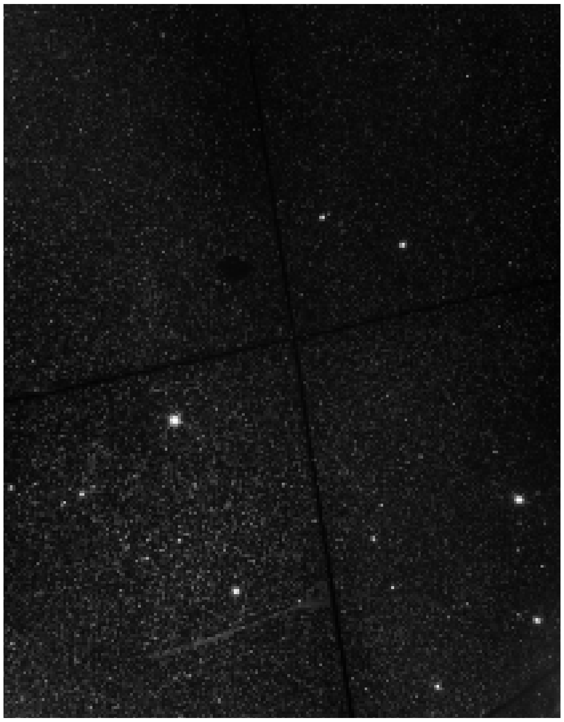

Figure 3

made, inorganic structures. For instance 'Bottle No. 3', (figure 2) flashed with light, shows the visible, co-equal circles, which are uniform depressions made in the glass, as well as an invisible system of diffused patterning. This second, invisible trace layer reveals perfectly symmetrical hexagons, as would be the case with organic living cells forming a tessellation pattern of tissue membranes.

'Fallen Sky', (figure 3) from the series *Walking in the City*, is an example of formless (uncontained) matter seen in a wide-open, ever changing field. One day the sight of mica twinkling on the city sidewalk momentarily shared, in my imagination, an affinity of pattern with the heavens. Due to the abundance of man made light and the absence of stars in the city's night sky, a wish image submerged in my unconscious, surfaced at my feet. I was walking with a friend who confirmed my whim: "Everything," she said, "is stardust." Like a photogram, the twinkling movement of light refracted on the lens of my camera. At 1/500-second speed of the shutter, a unique moment, never to be repeated exactly again, traced a familiar pattern of light and my projected desire.

It is from these points of reference that form is perceived. The beauty of an object emerges through photography's ability to generate its own image by way of its action—*drawing with light*. Perhaps the simplest and purest expression of how alchemical processes unveil original sources, the birth formation of an image, is seen in my last example (figure 4).

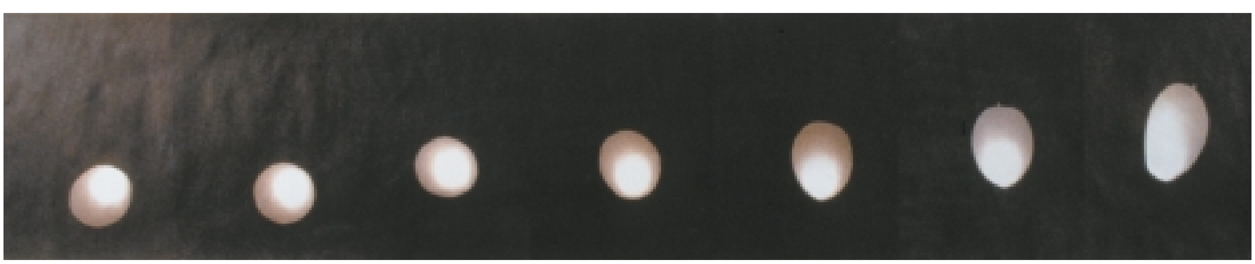

Figure 4

One Sun, One Apple, One Day charts the position of the earth (an apple) in relation to our sun over the course of one day. The sun's shadow moves east to west, arching. My wish was to make the turning pattern visible, like a solar clock. Here, on July 8, 1998, the length of one day in summer, relative to the earth's axis, is recorded. From under the shadow, where the apple was placed, we see illuminated the area that was protected from exposure. The elliptical shape traces intervals of time passing. By drawing directly with sunlight, a visual pattern of the fluid flow or turning of time is disclosed. Metaphorically, sound is visualized. Through our emotions we sense the object's presence and absence simultaneously.

Conclusion

In observing what takes place in phenomenology, particles are seen as part of a whole and gathered as part of a process. Rather than limiting the image to a single moment, a photograph can illuminate a flow of complex relationships, reflecting the dynamics of life. Working this way, what is recorded can be visually understood as the process of an image becoming.

Notes on Images

Page one. *Seed Leaf* 2001, gelatin-silver photogram

Figure 1. *Skeletal Leaf* (detail) 1998, Vandyke brown silver-sun print on Gampi paper

Figure 2. *Bottle No. 3*, (from *The Empty Bottle* Series), 1998-2001, gelatin-silver photogram

Figure 3. *Fallen Sky*, (from *Walking in the City* Series) 2001, gelatin-silver print

Figure 4. *One Sun, One Apple, One Day*, July 8, 1998, Vandyke brown silver-sun prints

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