THE BACKSTAGE OF VITRUVIUS' ROMAN THEATRE

A New Method of Computer-Aided Design that Reduces the Gap between the Functional and the Operational[1]

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Abstract. Computers are increasingly being used in professional design studios and by students of Architecture. However, their use is limited to technical functions (*tekhne*); what one usually calls computer-aided design is often no more than computer-aided drawing. In this research paper we reflect on the architect's work methods, and suggest an approach to design based on the "projection" of properties of the object (i.e. operators), rather than by geometric primitives. We propose a method of design using procedural models, and encourage a reevaluation of current programs of study with their traditional subdivision into separate disciplines.

By means of a procedural model of Vitruvius' Roman theatre, we show that, from a generic model we can produce a three dimensional (volumetric) model with all the characteristics belonging to a single family of objects. In order to clarify the method of construction, we use a functional language that allows us to model the actions. Similarly, we can use this functional language to encapsulate the properties of the building.

The scientific result of this experiment is the understanding and confirmation of the hypothesis that, by means of computers, we can find operators that help the architect assimilate a complex building design.

Key words: Architecture, CAD, Discipline, functions, modeling , operator.

1. Introduction

The goal of this paper is to present a new method of design in Architecture. This method uses the computer as a means of uniting the various disciplines entering into the architect's profession.

In order to present this method, we analyze the distinctive characteristic of Architecture as being a link between the functional and the operational. We examine the results of studies concerned with obstacles to the use of computers in design and, by means of a procedural model based on the description of Vitruvius' Roman theatre (first century BC), we use the computer to obtain configurations controllable by means of a functional language.

[1] http://www.cegep-st-laurent.qc.ca/depar/archi/caadria99

2. The distinctive characteristic of Architecture: the art of building a link between the functional and the operational

To speak of Architecture is first and foremost to speak of design, idea, image, symbols, and the human.

To speak of Architecture requires the adoption of a morphological language that communicates by means of combinatorial systems from the point of view of the meaning, the method and the means (Duplay, 1985). These parameters have, in the evolution of the architectural process, fallen by the wayside because the architect's modus operandi is a representative method that goes from sketches to plans and cross-sections, to subdivide space into planes that "contain and divide" it.

This approach is the principal cause of our difficulty in understanding the use of space in Architecture. Ultimately, the goal of plans is merely utilitarian, if not technical, for the purpose of execution of the architectural project. In reality the building and its construction are not merely a set of solutions to technical problems: they are "the set of measurements of the void, of the internal space in which man lives and walks". (Zevi, 1959)

An architect uses a drawing as a tool, and it is this purpose that has brought him to the drawing and to the reductive choices of the architectural viewpoint by simplifying the notion of project and by reducing, from a systemic point of view, the complexity of the building instead of considering this complexity as a given.

The drawing is transformed, in the studio, into a simple geometric system that facilitates the realization of the building, while its value as a design tool is disregarded. The same thing happens to computer-based tools where computer-aided design is nothing more than computer-aided drawing, forgetting that the design tool is first and foremost a tool permitting reflection: a non-synthetic and non-semantic means of developing an idea, anti-perceptive to reduce the distance between the representation of the building and its final result.

We see the computer as being an instrument of synthesis that allows us to represent the key actions of the architect during the design process. Our hypothesis is that it is possible to translate the logic and the history (logos) of the construction process by an algorithmic description, and we examine ways of producing these translations.

The treatises on Architecture, *De Architectura*, by Vitruvius (first century BC), then Bullet's *L'Architecture pratique* (1691), followed by Rondelet's *Traite sur l'art de batir* (1802), and Durands *Precis d'architecture* (1825), lead us to understand and to geometrically represent the objects described, but not the know-how involved in their design. Vitruvius himself, followed in the Renaissance by Alberti and several other thinkers, reminds us that "when necessary one must call on the architect's inventiveness in order to find new expedients" (Dalmas 1986), and that certain implicit rules must be followed.

Already at the end of the fifteenth century Pier de la Francesca, in *De Prospectiva Pingendi*, proposed new research in which euclidean geometry was enriched by notions of projective and descriptive geometry; by relations between space and physiology, between the visible and the invisible. «*To visualize an architectural object is to present it to one's vision or to one's mind in such a way as to perceive some chosen aspect of it.[...] We mustn't forget that, for the architect, the object doesn't exist, but must be invented. (Bourdon, 1989)*

We operate from within a paradigm which leads us to representations by means of parametric functions which, when expressed algorithmically, give us a procedural model of the design. This model should permit us to understand and conceive of a seminal environment where graphical representation is not reduced to the mere role of a sign or an image. This approach should open new avenues permitting the addition of the logos to the metaphorical equation of the representation where the drawing replaces the written word in the process of clarifying our thoughts. (Ferro, 1987).

3. Computer Science and Architecture

The epistemological status of computer-aided design is, as pointed out by Le Moigne, a highly controversial topic, hotly disputed between different schools of thought, including those of mathematicians and computer scientists. (Le Moigne, 1986) We are today at a turning point where we can envisage important changes to the current practice of Architecture; changes resulting from a convergence between Architecture and Computer Science, while maintaining an interdisciplinary approach that reflects the various skills of architects, urban planners, engineers, computer scientists, and other participants in the design process.

In this vein, already at the beginning of the seventies certain researchers, among them M. Tribus, proposed a re-adaptation of computer languages by detaching them from the procedure of problem solving. Tribus, in developing his theory of the project, proposed a systematic plan for the decision-making process in a project. He reminds us that, at each stage of the project, we must make decisions, some of them irrevocable, and this on the basis of partial information. (De Paoli, 1997).

To avoid the feeling of frustration experienced by an architect in a CAD situation, communication with the machine should allow for the conception of a language common to the man and the machine, a language sufficiently simple to suit the person, and sufficiently precise to suit the machine. A brief language without complicated formulas, (Ganascia, 1993). The problem today lies not in the memory capacity or the calculating power of the computer, but rather in our ability to provide coherent and relevant instructions. It is a question of communication between the participants in the architectural project and the machine.

Research in computer-aided drawing, in the course of the past decade, gives an increasing importance to ergonomics and cognitive science. In fact, if from the purely computer-scientific perspective the development of expert systems and methods of communication has attained a certain level of sophistication in the processing of information, on the level of cooperative dialogue with the computer, there has been considerably less progress. So much so that today in the domain of Architecture we cannot speak of computer-aided design. This article suggests a solution allowing the user to be aided by the machine, without being replaced by it, in difficult tasks such as decision-making in the course of the design process.(Garcia 1991)

We find that this approach involves a type of dialogue that pays more attention to human factors, that is, an approach where the human user plays a controlling role in the major decisions. This approach could influence architects in permitting them to overcome the obstacles keeping them from getting the most out of this new presence in the studio. The computer could then replace the traditional tools used in the elaboration of the project.

We wish, by means of this approach, to specify and validate operators helping in the design and construction of a unique three-dimensional model., where the design involves the properties of the object to be built; such as light, acoustic, or construction materials, to arrive at a complex conception of the model that takes into account the shape, the description of the building and this underlying knowledge that we cannot model.

This approach requires a precise geometric description of the object, and to attain this goal we describe the shape by means of an approach that enables the description of the logical properties of the object . In this manner we propose the creation of procedural models which will be the tool used in the design process that will allow the architect to overcome the blockage he is faced with when using the computer as a design tool.

3.1. THE THEORETICAL FRAMEWORK OF ARCHITECTURE: THE DESIGN

Computer science is not an end in itself, but rather the knowledge and mastery of these new tools which allow the architect to shed new light on problems related to design, help improve classical methods, and accelerate the development of new methods used on the elaboration of the architectural project. Thanks to computer science, we evolve towards a project which consists in establishing a bridge between classical and modern architectural methods. (De Paoli & Marty, 1994)

A study we have done of computer simulation and the work methods of architects has revealed a blockage with respect to computer-aided design. We have identified this blockage as being a restriction on "the exercise of taste", and it is manifested as the impossibility of telling the computer about the properties the architectural work should have in order to extract a representation that expresses the creation process, the constructive logic and the dimensional constraints or the relation to other types of non-geometrical information: the architect's freedom of choice is restricted to a collection of geometric primitives, which fail to express the architectural concept.

Other studies as well confirm and emphasize this blockage. For example, M. Leglise, in describing research in the domain of computer use in Architecture, reminds us that «the so-called computer-aided design tools are generally, in the field of Architecture, merely instruments for the project. One too often forgets that the main goal is simply getting them to "work". Among the principal criticisms of these applications, certain authors mention the preeminence of ways of manipulating geometric figures, to the detriment of schematic aids on all levels, including, of course, the verbal. (Leglise, 1997)

Upon reading the Ten Books of Architecture of Vitruvius, we find a similarity between the conceptual activity of the Roman architect who, constrained by rules of the classical orders and the code, was in danger of having to limit his designs to an inflexible style of architecture if he didn't call upon "the proof of talent as well as of knowledge; the ability to make all the essential modifications, as required by place, beauty and function" (Dalmas, 86) It is precisely this talent and this knowledge that architects still cannot express by means of computer-based design tools.

In Roman times the method of construction was based on operators that made it possible to build similar theatres. Indeed, the parameters could vary, but they could not evolve; the architect could not modify the scale or the value of the ratios fixed by Vitruvius' code.

3.2. THE STRATEGY OF ARCHITECTURE: AN INTRODUCTION TO COMPLEX THOUGHT PROCESSES

Necessitas, commoditas, voluptas.These three Latin words encapsulate all the work done by Vitruvius(first century BC), Alberti(1404-72), all the way to research done in the sixties by C.Alexander, attempting to find a rational basis for the architect's way of working and processing information. In his treatise on Roman architecture, Vitruvius establishes the rules of art which form the foundation of this work, and which A.Dalmas, in his translation of the works of Vitruvius, summarizes as follows :

- *the volume of a building should emerge simultaneously with the plane, the cross section and the facade;*
- *the building itself should be placed in the context of the site*

- *the choice of site should be determined by the climate*
- *the building's beauty is the result of the most direct possible expression of the purpose the architect had in mind for it.*

These parameters : proportions, harmony, climate, and beauty , are to this day absent from the context of CAD, and this prevents the architect from evolving fully in his mastery of computer-based design tools.

By means of a procedural model of Vitruvius' Roman theatre, we wish to understand and explain that, by means of a generic model, we can produce a volumetric model whose characteristics belonging to a single family of objects. Such a model allows us to illustrate the result of procedures, to find relationships among buildings based on their method of construction, and to verify the validity of a rule characterizing a set of objects(Parisel, 1997). In order to express the method of construction, a functional language makes it possible to model actions (Tidafi, 1996). In the same way, this language can capture the building's properties.

E. Morin reminds us that "the difficulty with complex thought is that it must deal with a hodge-podge of inter-retroactions, with consistency among phenomena, with fog, uncertainty and contradictions. Nonetheless we can fomulate some conceptual tools and principles for this venture, and we can envision the new paradigm of complexity which should emerge."(Morin, 1997; p.22) The correlation of a building's construction with its properties is a further step in this direction, that of an open system. We believe that by means of the computer, architects will be able to navigate expert systems, going beyond what C. Alexander and numerous other researchers since the sixties have been calling "problem-solving".

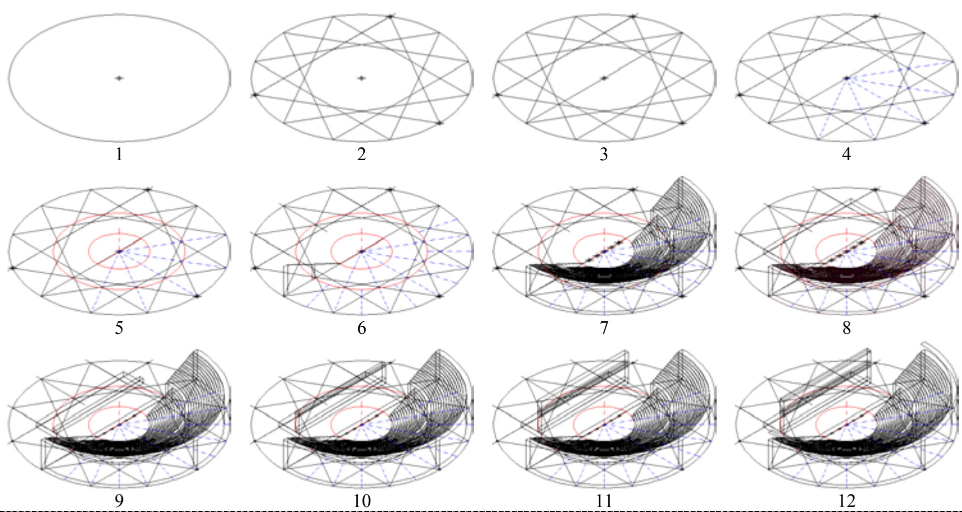
The issue, then, is to obtain a representation not just by means of a realistic volumetric model, but one which "governs" facsimiles of construction and design processes.(Rotge, 1998)

4. Model and Description of the Experiment

The formal description by Vitruvius of the Roman theatre allows to interpret the operations involved in the construction, and to group them into classes (modules) which we have translated to functions by using a functional language (SCHEME). We can visualize these classes by means of a modeling program (SGDLsoft). The representation consists of a series of three-dimensional images which transform constructive and temporal reality.

The table1 describes our research strategy: application and analysis by primitives of Vitruvius' roman theatre and analysis by geometric primitives and operators;

TABLE 1. Application and analysis by geometric primitives and operators



De conformationes theatri facienda
(Vitruve, traduction de A. Delmas 1986)

	(Vitruve, traduction de A. Delmas 1986)	Operator analysis
Frame 1 :	The plan of the theatre is to be constructed as follows: having placed the center, draw a circle whose circumference forms the perimeter of the theatre;	Circle
Frame 2 :	Inside this circle, inscribe four equilateral triangles, equally spaced and whose vertices touch the circle and subdivide it as do the astrologers in placing the twelve signs of the zodiac, when they are making computations from the musical harmony of the stars.	Astronomy<->music
Frame 3..	Vitruvius description...	Vitruvius operator…

4.1. HOW CONSTRUCTS THE MODEL

The architecture is a language who expresses, by combinative systems, the point of view of the sense and the methods. This allows to affirm that the architecture is the result of a idea who materialize the complexity of building by the inclusion of the parameters who define. We want to model, by some functions, and to render operational these parameters, called operators.

TABLE 2. Definition of design parameters

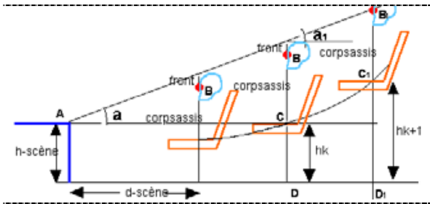
(define **centrum** (vector 0 0 0 1)) (define **primo** 10) (define **ultimo** (+ primo (* nombre-sieges d-siege))) (define **rapport-vitruve** (/ 2 4)) (define **nombre-sieges** 20) (define **d-siege** 1)	Design parameters by Vitruve.
(define **h-scene** 2) (define **d-scene** 4) (define **front** .4) (define **corp-assis** 1)	Design parameters by new function: Visibility in addition to design parameters of Vitruve (table 3)

During this experience we wanted to consider the computer like a tool of aid to the design who, in the first place, permit a reflection, This tool must be semantics in order to permit the development of the idea and to permit the reduction of the gap between the representation of building (the functional) and its result (the operational).

4.2. THE FUNCTIONAL LANGUAGE AND THE LINK BETWEEN THE FUNCTIONAL AND THE OPERATIONAL

The innovative characteristic of this experience is the possibility to modify and to add functions to a model; we could transfer the know-how and more precisely we could treat the prototypes of buildings with their complexity from the first act of design. In this manner we operate the link between the functional and the operational. In its description of theater, Vitruve presented some criteria of construction: the volume, its site, the climate and its beauty. We demonstrated that it is possible adding to these properties some new functions, for example the visibility of the seat level by each spectator under a same angle.

TABLE 3. Visibility of the seat levels



Algorithmic translation of visibility fonction (seat level position position) :

$$\mathbf{hk+1} = \frac{\mathbf{hk} + \mathbf{corpassis} + \mathbf{front} - \mathbf{h\text{-}scène}}{\mathbf{d\text{-}scène} + ((\mathbf{k} - \mathbf{1}) * \mathbf{d\text{-}siège})}$$

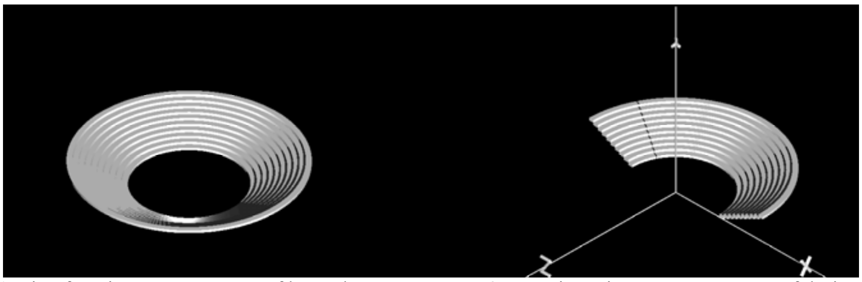
By the functional approach we could define some functions and to define a model who will serve of aid to design. One more we can take benefit of some generated functions for other constructive methods and insert them in a new process of construction. By the same way that in the evolution of building and its history, there is a transfer of know-how, in the same manner we could proceed to a transfer of know-how a procedural model in order to create libraries of specific functions. These functions allow not only the fast and efficient modeling of all building belonging to the same cultural area, but also transfering the know-how to the cultural subsequent areas.

TABLE 4. Exemple of two instances of procedural model (frame 2 et 8 of table 5)

(define M-theatre-vitruve (Dluni (coord_xyz .1) (Dlint (M-gradenes-Vitruve 10) M-forme-vitruve)))	Theatre with the design profile by Vitruve Theatre with the design profile by Vitruve, 10 seat level and plan of theatre
(define M-theatre-vue (Dluni (coord_xyz .1) (Dlint (M-gradenes-vue20) M-forme-vitruve)))	Theatre with the design profile by Vitruve and visibility function Theatre with the design profile by Vitruve, 20 10 seat level and plan of theatre

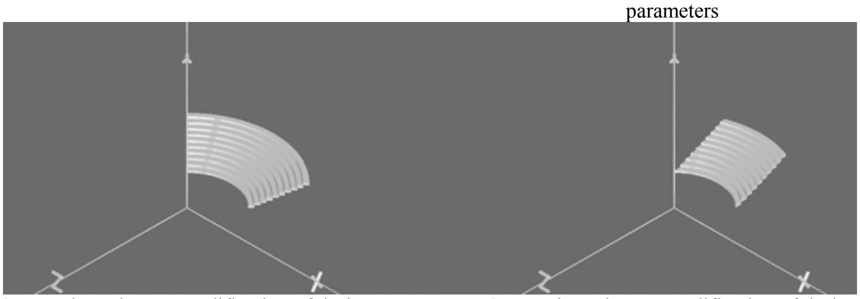
Finally the functional links the operational with this double parameter system : a building becomes an assembly of functions, a meta-function who give a definition that understands the complexity of building by some lines of programming and not only on morphological side, but also on process side of design.

TABLE 5. Different buildings created from a procedural model, by modification of functions and parameters



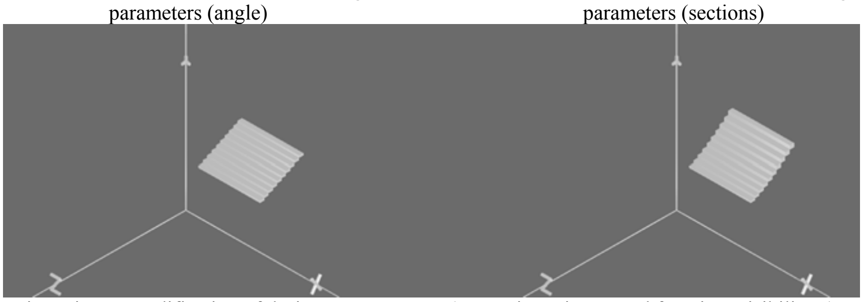
1. First function: management of know-how

2. Function Vitruve: management of design parameters



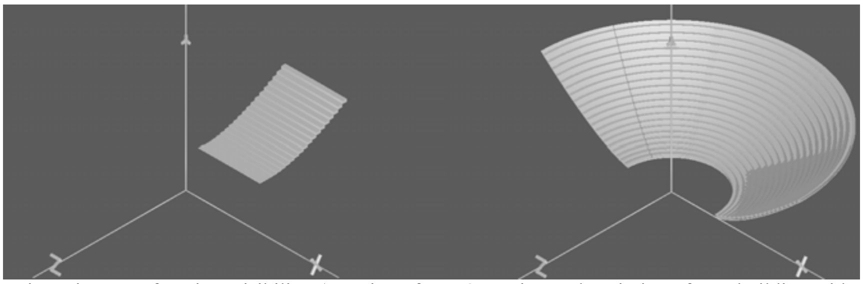
3. Function Vitruve: modification of design parameters (angle)

4. Function Vitruve: modification of design parameters (sections)



5. Function Vitruve modification of design parameters (contour of seat levels)

6. Function Vitruve and function Visibility (crossing of functions)



7. Function Vitruve et function Visibility (crossing of functions) et modification of parameters, N. of seat levels)

8. Design et description of new building with the genesis of Vitruve' functions and Visibility function with modification of parameters

7. Conclusion

This procedural model is intended to be an example of integration of the object's properties with geometric primitives. The scientific contribution of this experiment is the understanding and confirmation of the hypothesis that we can , thanks to computer-based tools, get a handle on operators allowing the architect to assimilate a complex conception of the building.

In a previous article, we concluded that the use of a shape grammar for the actions, and a nomenclature for the operators allowed us to understand the actions of the components and to establish a strategy for improving the methods of representation. (De Paoli, 1997) The results presented enable us to assert that, by understanding architectural objects in terms of their topology and their properties, we can improve the methods of representing them; and that these objects are qualitatively and not just geometrically related.

If we consider Architecture to be a complex set of procedural models by means of which a set of properties becomes a material object, we can describe the architectural process algorithmically; creating variables (called "attributes" in object-oriented programming) that distinguish one object from another by describing its state and its appearance. These characterizing variables, which we can qualify as behavioral, are modified when the object interacts with another. This means that we can model a set of actions on a class or a set of properties. For example, one can change the characteristics of the theatre not just on the level of shape and size, but also in terms of visibility and acoustics.

This descriptive mechanism is extremely powerful, as it makes it possible to establish relations between the functions, i.e to create classes in the sense of object-oriented programming, and leads to a greater economy of means in the course of procedural model-based design.

Finally, this possibility of enhancing functions through other functions yields insight into the goals of the architectural process, where the properties of the building inherited from the characteristics of common classes give rise to a new representation and a completely new design process.

Today the use of computers allows us to transform a description into a function (in the end the function replaces the writing), and to subdivide the function into sub-functions. For example, in the case of the theatre we have step functions and angle functions. These constitute a class, in the sense of object-oriented programming.

This approach makes it possible to construct a volumetric model by adding a fourth dimension, that is to say, a new dimension consisting of all the events entering into the construction and which permit us to generate a model based on specified parametric functions which we call generic parametric functions.(Parisel, 1998) In the case of the theatre, for example, the computer-based tools make it possible to add to the Vitruvian description a new dimension giving the architect more leeway in the creative process than allowed for by the simple use of geometric points and lines.

In the end we can explore the properties of the object to be created: light, acoustics, harmony-- as suggested by Vitruvius--and we can explore our object until its final realization, while keeping in mind its constructive genesis. We are reminded of the etymological significance of the word 'symbol": *symbolum*, which represented a clay object that was broken in two by the host upon departure of his guest and which would provide lasting proof of the relationship between the owners of the pieces. Analogously today we define a symbol as being a figurative sign that represents a concept, is its image, its attribute in accordance with a logical correspondence.(Ganascia,1997)

Contrary to Vitruvius, who could not provide fixed parameters, today's computer-based tools make it possible to create an evolving function that permits us to create new models that could be represented in a completely different manner from the model we started with but maintain the same properties.

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