The Front of the Stage Of Vitruvius' Roman Theatre

A new Approach of Computer Aided Design that Transforms Geometric Operators to Semantic Operators

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Abstract: The driving force of all researches where the systems of computation are used, is the utilization of an intelligent method for the representation of building. The use of computer, in design process, is often limited to technical functions (*tekhne*), and what one usually calls computer-aided design is often no more than computer-aided drawing. In this research paper we continue a reflection on the architect's work methods, and suggest an approach to design based on the semantic properties of the object (i.e. semantic operators), rather than by geometric operators. We propose a method of computer aid design using procedural models where the initial state of design is vague and undefined.

We operate from a paradigm that leads to represent a building by means of parametric functions that, expressed algorithmically, give a procedural model to facilitate the design process. This approach opens new avenues that would permit to add the *logos* (semantic properties) and lead to a metaphorical representation. By means of procedural models, we show that, from a generic model we can produce a four dimensional model that encapsulate a volumetric model with semantic characteristics. We use a meta-functional language that allows us to model the actions and encapsulate detailed information about various building elements.

This descriptive mechanism is extremely powerful. It helps to establish relations between the functions, contributes to a better understanding of the project's aim, and encapsulates the building properties by recalling characteristics of common classes which give rise to a new configuration and a completely original design. The scientific result of this experiment is the understanding and confirmation of the hypothesis that it is possible to encapsulate, by means of computing process, the links between design moves during conceptual and figural decisions and transform the geometric operators in semantic operators.

1. INTRODUCTION

The linear approach that permitted the development of the first systems of computation didn't allow a full development of a computer architectural language that takes into account, in phase of design, the architect must develop a complex approach. This method followed the same thought of simplification in the representation used in architecture since the Renaissance. Since that period the drawings are just a part of the information that we want to symbolize and they don't express the design: it is only a geometric representation of building with more or less details.

These considerations allow us to affirm that, in order to obtain a real aid to the design process, the computer tool must not be used like a tool to resolve problems, but like creation tool in design situation. This approach permits all the actors of architectural project to call for the presence of the computer tool in conceptual understanding.

In order to understand this approach we analyzed the distinctive character of the architecture. We studied the results of the researches on the understanding of jamming that limit the utilization of the computer for the design. By way of one procedural model constructed from the description of the Roman theater by Vitruve (First century BC) we asked the computer to act like a tool that allows us to obtain some figurations that can be "governed" by a functional language (De Paoli, Bogdan, 1999).

Subsequently we concentrated our efforts on the assessment and the optimization of various building functions like the acoustics and the visibility in order to see how a functional language could create a system of intelligent representation of building. For it we studied several computer postures: the representation of scenes by the declarative design (Popova, De Paoli, 1998), the functional language for the creation of procedural models (De Paoli, Bogdan, 1999) and finally the complex management of semantic meta-functions presented in this article.

We are going to present our experiences that suggest a change of paradigm for the architectural figuration and the utilization of the data processing during the phase of design. We demonstrate that the computer, by the slant of the utilization of semantic operators, is not only a tool of aid design situation, but also a tool to develop an understanding of the building's properties in a collaborative design situation.

2. LANGUAGE, THOUGHT AND REALITY: AN APPROACH INTELLIGENT TO THE ARCHITECTURE

Every time we study language and we try a principle of its theoretical implementation we have the obstacle of the limitations of linear reasoning:

expressing a model by a language is always an approximation of patterns and an imprecision of the object. For example during the design process we are confronted to some different paradigms: the one is the design of form and matter and the other one the work in the space-time and in the space-world. Presenting these aims and transposing them in terms of conceptual interaction and convenient applications means to change the paradigm of design used until present: «The architecture is like a big sculpture where men penetrate, march, live». (Zevi, 1959)

If we affirm that the architecture is the materialization of combinative ideas of parameters that define the complexity of building, we could suggest to model these parameters, that will be named semantic operators. «Design problems are, as a rule, ill-defined. This implies that the initial state of a design problem may be vague, its goal state not clearly definite, and that no algorithm is available for the "journey" from the initial state to the goal state» (Goldsmith, 1997).

Therefore, like underlines it Goldsmith, we think of the typical design as an indeterministic and complex problem, whose solution necessitates a search. «A solution to a design problem is a design proposal». We want by this approach in the CAO to suggest a way that modifies the present aim of the representation: "manufacture" of utilitarian plans, in truth technique plans for the realization of the architectural work, where these plans are principally a set of resolutions of technical problems. To add semantic problems to technical problems means to choose a figural representation and to analyze, by the way of meta-functional languages, all of the measurements and properties of the space, where men walk and live.

Actually the drawing is transformed, in the workshop, 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 semantic means of developing an idea, to reduce the distance between the representation of the building and its final result. (De Paoli, Bogdan, 1999)

The aim of this article follows some studies during the last ten years by researchers and professionals, on the understanding of the jamming that limits the utilization of the computer during the design process and on the explanation of the links between the visual communication and the data processing. We see a computer as a tool to put together the actors of the building process and to represent the essential operations of the architect during its design. "We want to explain the problems to solve in order to establish a common language between the different actors and suggest some ways of solution, while taking into account that the architect developed a language and some methods of work adapted to the 2D representation, and suggest a modification of language for the figural approach that encourages the full exploitation of this technology." (De Paoli, 1997) 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. It is also possible to operate, during the design process, with some semantic operators like acoustics or visibility. Our preoccupation is the study of the methods in order to transmit these translations by a functional language and a figural approach. In fact, researches of this last decade, oriented toward the modeling of the actions and the process of architectural project, reinforce the idea that these operators could be transformed in functions, and give a geometric and representative result, or, like suggest some researchers, a figural representation.

We want, by our gait, to specify and to validate some operators who help in computer design and to build a unique model, where the design passes by the definition of the properties of the object for design like the visibility, the acoustics or the matter, in order to arrive at a complex figural approach.

3. THE SEMANTIC STATE OF THE ARCHITECTURE : THE DESIGN BY DECLARATIVES SCENES AND PROCEDURAL MODELS

A research that we achieved on the methods of work of architects and the computer simulation put in evidence a jamming facing the utilization of the CAO: the impossibility of transmitting to the computer the properties that the architectural model must have in order to extract a figural representation. A figural representation expresses the process of genesis, the constructive logic and the constrained dimensions and the dealings with types of non geometric information but the liberty of the architect's choice is limited by the actual software to the assembly of primitive geometric, that doesn't express the idea. For it, we studied the languages of programming in order to understand some ways of solution. We demonstrated that to design with a computer it is necessary that there is a situation of interaction casual-probabilistic (Popova, De Paoli, 1998). This approach seems very coherent with the characteristic of the declarative methodology, permitting a certain inaccuracy and incompletion of the description. In sharing the means of description by classes it insures the possibility of designing some scenes (models) starting from a partial description of the properties.

With this type of language the rule of the macroinstructions on superior levels provide a method for modeling the design tasks like methodological knowledge. The rule of the macroinstructions of descriptions is a link of causality destined to construct a basis of causal probabilistic knowledge containing the identification of nodes on the causes and effects and the links of causality between these nodes.

In a second research project where the main goal was to model construction techniques for Byzantine vaults, as well as the know-how of the Byzantine themselves, we were able to understand and explain the relationship between the functional and the operational. The functional is the purpose (function) of the vault, and the operational is the expertise (know-how) of the builders (Bogdan, 1997). This allowed us to continue our researches in order to try transferring this knowledge to other moments of history and to transform this meta-function in models that will be named procedural.

By the heritage of this model we have created a procedural model of Roman theater of Vitruve, in order to understand and explain that, by a generic pattern, we could produce a model with all features which belongs to the same family of objects. This pattern allows illustrating the result of processes and proving the relationship with the buildings by their process of construction. In order to express the method of construction, a functional language permits the modeling of the actions. This functional language permits to encapsulate the properties of building. (De Paoli, Bogdan, 1999)

4. MODELING AND DESCRIPTION OF EXPERIENCES

The figuration (figural representation) consists in a series of three-dimensional scenes which metaphor semantic, constructive and temporal reality to validate the hypothesis: it is possible to encapsulate semantic properties and to design, in computer environment, with procedural models. We choose for the end of the experiment the formal description of the Roman theatre by Vitruve, which allows us to interpret the operations of construction and to group them in modules (classes) which we translated into functions by the use of a functional language (SCHEME) and we visualized these modules by a program of solid modeling (SGDLsoft).

Thereafter, we added a semantic operator, the visibility and we proceeded to the declarative design of scenes which interpret these operations. Finally we added our current knowledge in acoustics (for example reverberation) and we created models for design process that could be used in draft and sketches by designers.

The following programs and tables describe our research strategy :

• TABLE A. Program and Representation by geometric primitives;

• TABLE B. Program and Representation by functional language;

• TABLE C. Representation by crossing geometric and semantic operators;

• TABLE D Transformation of functions for semantic properties.

4.1 Program of representation by geometric primitives

In this case we studied the result of a geometric description, it is a pattern which data are "imperatives". The transcription in DXF format is a professional language description. The parameters are frozen, they must be defined to the starting point: the program executes some data which express the geometric relationships only (Figure 1). Some operators described by Vitruve, such relationships between music and astrology could not be interpreted.

TABLE A. Program and Representation by geometric primitives

Operator Analysis

De conformationes theatri facienda (Vitruve)	Operator analysis
The plan of the theatre is constructed as follows: having placed the center, draw a circle whose circumference forms the perimeter of the theatre;	Geometric operator: Circle
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. …	Semantic operator: Astronomy<->music

Example of Vitruve pattern, by "imperative" and linear computing

0 SECTION 2 HEADER 9 $ACADVER 1 AC1009 9 $INSBASE 10 0.0 20 0.0 30 0.0 9 $EXTMIN……......... ... $LTSCALE 40 1.0 9 $ATTMODE 70 1 9 $TEXTSIZE ➪	➪ 0.2 9 $TRACEWID 40 0.05…… ………… VERTEX 8 LAYER-1 6 CONTINUOUS 62 7 5 39 10 0.0 0 VERTEX 8 ………………… VERTEX 8 LAYER-1 6 CONTINUOUS 62 ➪	➪ 7 5 3A 10 7.339467 0 VERTEX 8 ………………… LINE 8 LAYER-1 6 CONTINUOUS 62 5 52 10 9.181379 ………………. 11 0.0 0 ENDSEC 0 EOF Etc…	Translation: DXF description

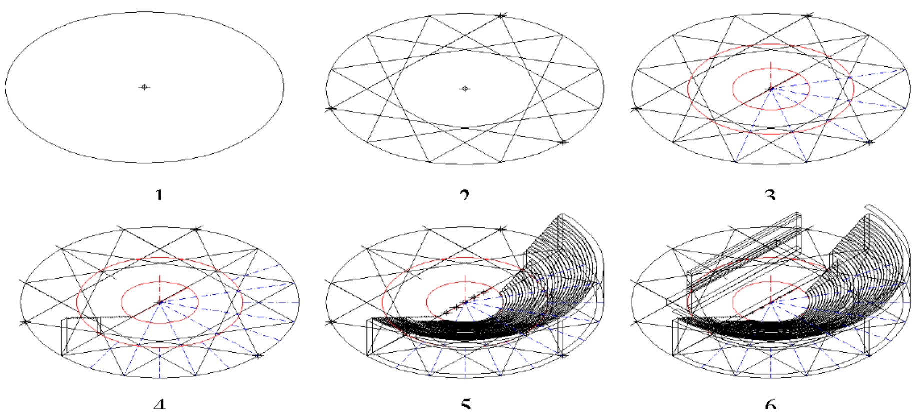


Figure 1. Exemples of Vitruve Description (Geometric Operator)

4.2 Recuperation of knowledge by some functions

The first innovation of our gait was the recycling of functions. This way has two advantages: the first one is a computing fluently and the second one a transfer of know-how. In this case, for example, we took some functions created for the modeling of the Byzantine vaults and, modifying the parameters, we transferred them to the construction of a theater platform.

It is possible to demonstrate that by the slant of a functional language we can model all the vaults constructed according to this functional principle and transferring this knowledge to other types of similar construction. This language is a functional language that permits the description, by the programming, of the logical purpose of design (Figure 2). In this case we transferred a function that shows a know-how in a function for a geometric construction: from the vault construction technique to the geometric construction of the theatre platform.

TABLE B. Program and Representation by functional language

Operator Analysis and functional language (SCHEME and SGDLsoft technologies)

Model of construction's process of the vault:

M-voutebyzantine (n, h, k)

n= width of the arch; h= subbasement; k= number of slices of brick.

The other elements, like the thickness of the arch, the depth or the slant of the slices, could be controlled in the script. (http://esi24.ESI.UMontreal.CA:80/~parisel/Voute/)

The functions (samples):

```
(define Mboules_controle
 (lambda (n h)
  (DLmax
   (DLatt
    (SDcolRGB
      (vector 0 1 0 1))
    (GDsphdis
      (vector 0.1 1)
      (vector 0 0 0 n)))
   (DLatt
    (SDcolRGB
      (vector 0 1 0 1))
    (GDsphdis
      (vector 0.1 1)
      (vector n 0 0 1)))
   (DLatt
    (SDcolRGB
      (vector 0 1 0 1 (GDsphdis
      (vector 0.1 1)
      (vector n 0 n 1)))
   (DLatt
    (SDcolRGB
      (vector 0 1 0 1))
    (GDsphdis
      (vector 0.1 1)
     (vector 0 0 n 1)))
   (DLatt
    (SDcolRGB(vector 1 0 0 1))
    (GDsphdis
     (vector 0.2 1)
      (vector (/ n 2) (- h) (/ n 2) 1)))
 )))
etc…
```

```
;;Visualisation of construction of the vault;;

(define Mprovisoire
 (lambda (n h k)
    (DLmax
     (Marc_diagonal n h)
(Mboules_controle n h)
     (M-boulesbleu2 n h k)
     (M-tousmorceaux n h k))))

(pisobs (vector  1.3 0.35 1 0))

(define Voutebiz
 (lambda (n h k)
  (begin
   (pistarget (vector 2 1 2 1))
   (pisbox (vector 12 8))
   (PIswin (vector 900 600))
   (PIview
    (PIgen
       (Mprovisoire n h k )
       "marius")
"marius"))))
```

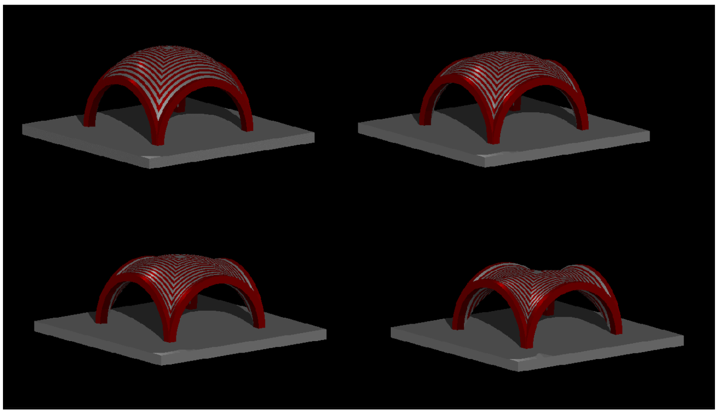
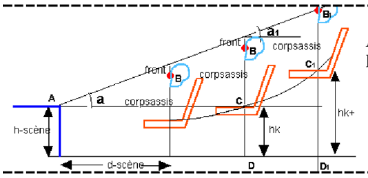


Figure 2. Example of simulation from construction's techniques of Byzantine vault

4.3 Creation of a modeling program by functions

In an article entitled *The Backstage of Vitruvius's Roman Theatre*, we demonstrated that it is possible to cross some geometric parameter with one semantic property and we chose the visibility as the semantic operator. This operator could not be represented by the imperative and linear representation. The description of architect (Vitruve) is vague and it is necessary to create a function that permits the re-interpretation of results according to several parameters such as the height of the spectators (Figure 3 and 4). This would permit, for example, to simulate the model for a children's theater. Therefore these data must be crossed with geometric and imperative data such as the position of the seats. (De Paoli, Bogdan, 1999)

TABLE C. Program and Representation by crossing geometric and semantics operators



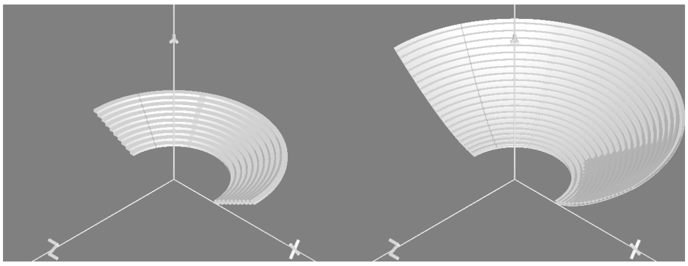
Algorithmic translation of visibility fonction (seat level position position) :

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

Figure 3. Examples of Vitruve Description (Geometric Operator)

Definition of meta-functions

(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 (



(define M-theatre-vitruve (Dluni (coord xyz .1)	Theatre with the design profile by Vitruve Theatre with the design profile by Vitruve,

(Dlint (M-gradenes-Vitruve 10) M-forme-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

Figure 4. Example of two instances of procedural model (Figural and Functional)

4 . 4 Transformation Algorithmical for Semantic Properties: Visibility and Acoustics

The demonstration algorithmical being made, shows that it is possible to transfer knowledge and cross some geometric and semantic parameters. In this last experience we present the final results of our researche: the creation of procedural models only by semantic properties for a design in declarative scene process. In this approach completely original we added the acoustics to the parameter visibility.

We are aware that, during the definition of the acoustics function, we must take into account a set of factors that goes from time of reverberation to the clarity and type of sound. For this experience we take in consideration only the reverberation factor in relation with the spectators position, and demonstrate that, in encapsulating the data of this factor and crossing it with the visibility already modeled we could simulate several procedural models.

The characteristic of these models is to be a set of scenes for a new approach to the declarative design. Like in the experiences presented on the declarative scenes researches, they permit an analysis casual-probabilistic and a design on a model not clearly defined, where the parameters make abstraction of the geometric data.

These models are based only on the definition of semantic operators. This approach means that the achieved model is not the Vitruvius Theater, but a model that understands some semantic operators. In our case the figural model can be a covered swimming pool, a movie theatre or a stadium for soccer game. We are acting as a designer figuring some forms and modifying some situations, for example: the position of the spectators, the priority of a certain type of reverberation or again of sound transmission time. The end is a figural conceptual sketch. (Figures 5,6 and 7)

TABLE D Transformation of functions for semantic properties

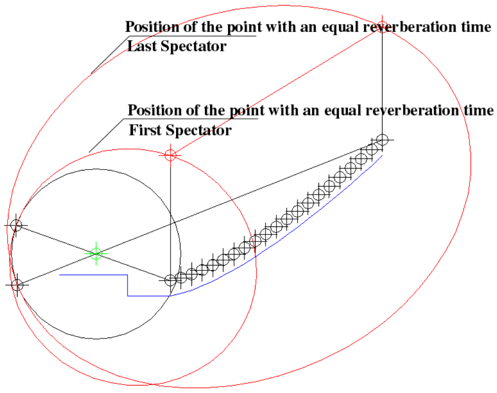


Figure 5. Acoustics and reverberation on multi-position levels.
The two ellipsis are the positions of the points with an equal reverberation time for the first and last spectator

Definition of meta-functions

(define visibility (lambda (view_angle) (m-relation (geometry (space)) (dimensions (spectators)))))	Visibility
(define acoustics (lambda (reverberation-time) (m-relation sound_source (spectators_position (visibility)))))	Acoustics

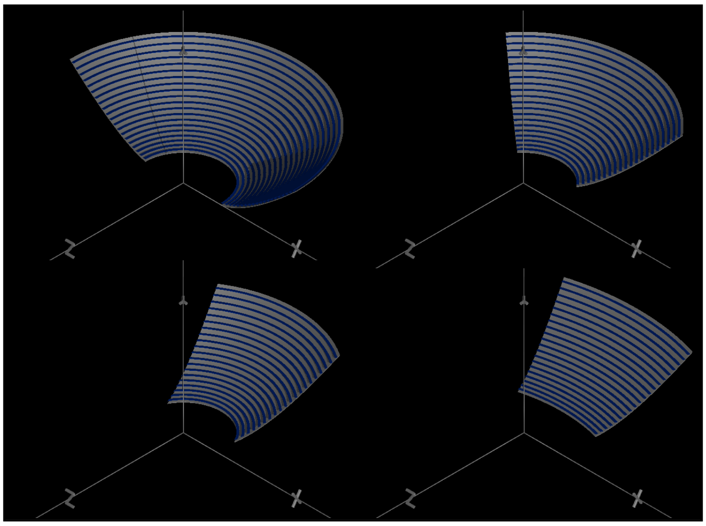


Figure 6. Example of instances of procedural model (Figural and Functional) obtained by interactions with geometrical parameters

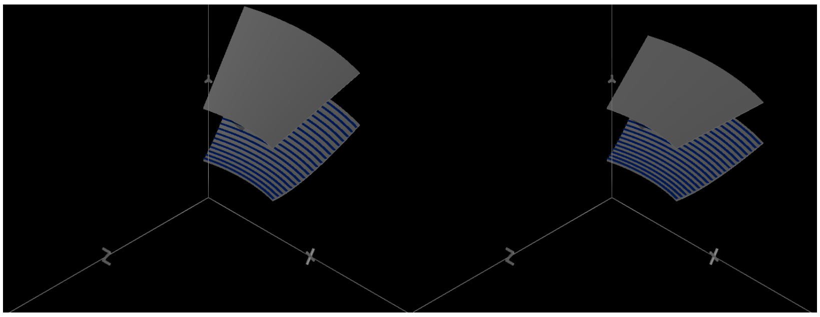


Figure 7. Example of instances of procedural model (Figural and Functional)

Example of semantic interpretations of procedural model: Visibility and Acoustics

(define theatre (lambda reverberation_time visibility_comfort) (Dluni (platform_seats (visibility_comfort) (roof (position_seats (visibility_comfort)) (reverberation_time)))))	By modifying the visibility comfort we obtain an other position for the seats and, consequently, a new position for the roof, that was “linked” to the seats by the reverberation time

5. CONCLUSION

The adoption of the computer by the designers passes by research toward some systems, manipulating at the same time the knowledge, the geometric and semantic properties of the scene and also on the process of design itself. These new systems based on languages of high level distinguish by the type of reasoning based on inferences (deductions, abductions) and on the utilization of an approach by models (scenes) rather than by numeric computing. This renders the process of computer design more explicit and more transparent (Popova, De Paoli, 1998) according to this gait the form is not the resultant of one solution, or a simple list of functions, but it is the result of a cybernetic activity. The functions (activities) are considered like a process of verification of the architectural idea.

Several points of view on this approach demonstrate how we could use the computers in order to change the paradigm. The designer could put back continuously the cognitive interpretations by new interactions, in all moments of the design-realization of model. Once more these interpretations are structuring: they interpreter a model in structuring the form. This feedback is made through an action on the environment and the expectation of the corroboration from the suggested structure. This form could not be exact and precise, because environment evolves; it is finally a whole of predictions, like it was a preliminary sketch composed by the architect on a napkin during a discussion with the client. One more new situation following this approach is the active and simultaneous participation of all the actors in the process of construction.

This mechanism of update recalls the reasoning *abductif* (Bourgine, 1989) which consists in emerging a new plausible hypothesis: as soon as an expected phenomenon is different from one observed phenomenon, we interpret the anomaly and we present a new solution. This is the basis of the design in architecture defined about the concept of representation of the properties, especially semantics.

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