



## New materiality: Digital fabrication and open form.

### Notes on the arbitrariness of architectural form and parametric design.

Carlos L. Marcos <sup>(a)</sup>

<sup>(a)</sup> Departamento de Expresión Gráfica y Cartografía. Escuela Politécnica Superior. Universidad de Alicante

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**Corresponding author:**

Carlos L. Marcos  
Tel.: (34) 965 903 400 (ext. 3188)  
e-mail: [carlos.marcos@ua.es](mailto:carlos.marcos@ua.es)

#### Abstract

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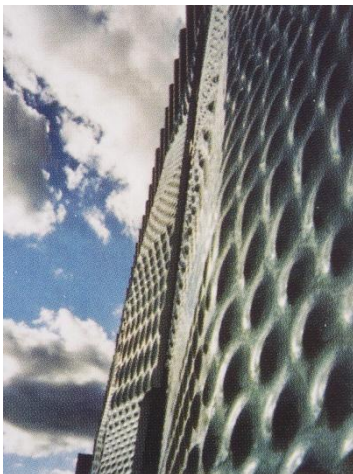
*Digitally conscious architectural design is founded on the assumption that computer tools should modify architecture's own language, not just the way architects must work.*

*The idea of open form is the result of producing encoded designs, that is: geometry is defined parametrically and codified in a non material language instead of being imposed over materiality –drawings or physical models- as is characteristic to architectural design tradition. A parametric design is open in as much as it defines a topological model where the connectivity between the parts and their relation to the whole generates a typology of possible designs limited by the range of parameters involved. Some parallels can be drawn with Eco's idea of open form referring to some artistic production of the second half of the XX century.*

*The increased complexity that can be achieved with new design tools has often led to a banal formalism inconsistent with architecture's own tradition. The baroque-ness of recent digital designs is confronted with the aesthetics of simplicity established by Modernism derived from its constructive principles. As Tafuri or Moneo pointed out, and recently Eisenman has proved with his own architectural production, there is a certain degree of arbitrariness in architectural form. However, architectural sense must rely on the principles of utility and construction. Thus, arbitrariness of architectural form should not be confused with arbitrariness of architectural design; it just refers to the fact that the complexity inherent to architecture may not optimize the relation between form and function. Thus, a variety of different architectural forms may well suffice the use requirements for each project.*

*Digital tools have improved the potential of architectural design thus broadening architecture's role and providing the apparatus to explore geometries and constructive systems that would have been unimaginable decades ago. C.A.D./C.A.M. tools are beginning to produce extraordinary synergies in the context of complexity. Digital fabrication is the logical extension to digital design as it relies on the computers' precision and their potential to manage complexity in varied ways, shifting from construction to manufacturing.*

*The aim of this paper is to analyse the relation of open form and digital fabrication. Conceptually, it will address what has been referred to as new materiality understood as the constructive logic intrinsic to materials and new fabrication techniques. New materiality may articulate an architectural constructive logic as stated by Milizia in the XVIII century and new digital fabrication techniques.*



**Fig. 1 Tool-Hide, Ron Klein, 2006**  
(Photo by Ruy Klein).

## 1 Architectural Canon, Difference and Repetition

Some architects and architecture historians think the advent of digital tools in architecture is just a mere shift in the way and the strategies architects work with. Although bearing in mind the fact that these new tools have greatly enhanced architectural design they have, however, dismissed the possibility of considering this change as a new paradigm in architecture that could affect architecture's own language.

On the other hand, nobody would doubt that Modernism introduced a shift in the architectural

paradigm; the use of steel and reinforced concrete not only changed the construction technology –something which they certainly did- but also affected architecture's conception introducing one of the deepest revolutions throughout history in the field. De la Sota [1] wrote about the parallels between new materials and new architecture and compared it to the change that the *pianoforte* introduced in music. Can anyone imagine Chopin's music and its rich exploration of the different sonorities to be found in the piano without the once new instrument? Moreover, an important part of XIX century Romanticism in music could not be understood without the new instrument: the piano changed music's language.

Le Corbusier's [2] *Five Points of Architecture* established a new canon proposing a totally new

grammar: the grammar of what became to be called the *International Style* [3]. Despite leaving aside modern expressionist trend it did serve as a new grammar that renewed architecture's language and reigned in the architectural arena during decades. What was then new in comparison to what architectural past paradigm?

For centuries architecture looked to the past seeking for architectural models that tried to emulate centuries after those models had been erected. Renaissance tried to revive Rome's classical architecture. Construction technologies were not very different but the rudiments remained the same, the syntax was therefore also equivalent. In addition, it was the architect's concern to reproduce those models and the language on which they were based. In terms of Deleuzian theory their position was that of *repetition*. It was their intention to achieve architectural authority through the repetition of those canonical models.

Conversely, models can also be criticised and design may produce alternatives as a result of such critic, something that would constitute *differentiation*. This issue very directly relates in our field to what Deleuze [4] addressed in his *Différence et répétition*; the relation between models -typological models in our tradition- and the production of architecture developed after them. Modernism in general and Le Corbusier's work particular are a fine example of *differentiation* in comparison to classicism, although they settled a new canon [5]. In fact, it was the change in tectonics the cause of the alteration of the syntax, but language was also drastically changed producing a new grammar. Picon [6, p.134-135] has written on the idea of history and memory regarding to the repetition and the differentiation of models on the following terms:

Above all, it was through the articulations, through the interplay of vertical, oblique and horizontal parts, between supporting and supported members, that tectonic related to time, history and memory.

Architectural tradition was questioned because steel and reinforced concrete allowed the concentration of vertical loads in extraordinarily thin columns liberating the layout and the facades of bearing walls. Consequently, partitions would only be membranes to be freely arranged and windows could span from one side to the other of the facade. Architectural language underwent a true revolution that constituted a change of paradigm. Somol [7, p. 9] has extrapolated Deleuze's ideas on difference and repetition to architecture as follows:

The first repetition relies on an ideal of the origin or model, an economy of identity, and can be thought of as typologically driven (the vertical imitation of timeless precedents). In contrast, the second sets in motion divergent series and exists as a continual process of differentiating. One points back to a static moment of being, while the other advances through modes of becoming.

The two main trends that could be considered within postmodern architecture –Historicist Postmodernism and Deconstruction- are good examples of *repetition* and *differentiation*, respectively. Historicist Postmodernism is

at the worst level of repetition for it uncritically repeats models of the past in terms of style and visual appearance but uses modern construction systems, steel and concrete ignoring the syntactical logic of bearing walls that supported classical architecture's language. In doing so, it is just a trivialization of classical ornament and formal repertoire; therefore it is false, untrue and anachronistic, a simple reactionary attitude confronted to Modernism [8]. Its absolute falseness can be inferred by the fact that the trivialization of classicism is founded on a superficial analysis of its *being* based on visual appearance and a ornamental repertoire of elements whose constructive logic is neglected and perverted by usurping its iconic and symbolic value within a well established language. Deconstruction in architecture, on the other hand, is a true example of differentiation. Being as it is at the opposite pole of Historicist Postmodernism, it takes Modernism as a reference but instead of considering it as a model to be repeated it goes beyond its syntactical limitations deconstructing the pure and closed geometries of the *International Style* breaking down the form into folding architecture. Conceptually it can be related to Deleuze's text, *Le pli. Leibniz et le Baroque* (1988), although formally has more to do with Analytical Cubism and, to a certain extent, with architectural Expressionism such as is to be found in late Scharoun's architecture. It is important to remark that the attitude of differentiating or repeating has little to do with style or formal appearance as it refers to the reason of reading and interpreting models. As Somol [7, p. 10] has wittily pointed:

Historicism in this account has little to do with style, but is more a mode of operating, since historicist work can equally include the modern, as evident in the projects of Richard Meier.

## 2 Digital Consciousness, New Design Paradigm and Open Form

On the other hand, some of us think the advent of digital tools have also brought a change of paradigm, not only a more efficient way of designing architecture. Just as deep as was the change introduced by Modernism, digital tools have altered the language of architecture itself. But unlike then, it is not a material based revolution, it is a conceptual one that operates in two different levels: the conception of the design itself and the constructability of it in terms of manufacture and assembly.

Computers have truly altered the design process and architectural conception. The change of paradigm is related in the first place to *complexity*, to the possibilities that computers offer in terms of conception, visualization and management of extraordinary complex geometries that could have been unimaginable and irresolvable without them. In addition, computers have also allowed calculating enormously complex systems of loads and stresses, and computerized robots have been able to manage the positioning and assembly of the customized constructive elements. We can refer to *digital consciousness* as the awareness on digital computing enhancements applied to architectural design. Thus, digitally conscious architectural design challenges modernist paradigm and proposes a new grammar in accordance with digital culture. Architecture can also be

*informed* by the new inputs and bits of information that digital culture has managed to spread. Every epoch has its *zeitgeist*, ours is undoubtedly build on information. Antonio Saggio [9, p.45] has referred to this influential environment that affects every one of us and must therefore be considered as a new determining factor in architectural design on the following terms:

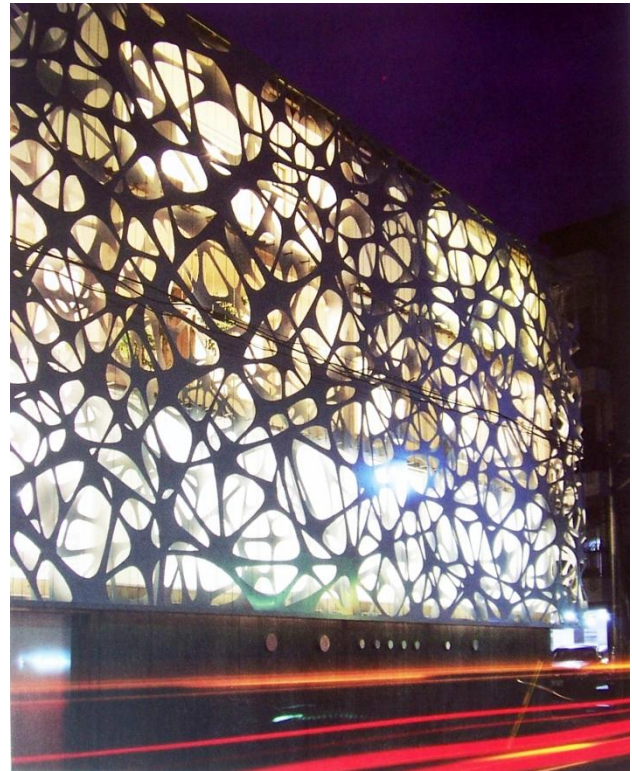
Our relationship with information technology (IT) is structural, cultural, and formal at the same time; *structural* because all of society rotates around the value of information; *cultural* because orienting one's self in this new scenario is fundamental; and *formal* because the procedures put into effect by this IT way of thinking can also influence the way of conceiving architectural form.

From the conception of architecture point of view, above all other considerations, what is probably the deepest change is that which refers to the idea of *open form*. Parametric and algorithmic architecture have greatly altered the process of design since they are coded based designs. *Openness* is possible because the geometry of the design is not embodied in a material existence; rather, it is defined through a code that stands for it. The generation of scripts that define geometries is topologically structured [10], being the relational definition of the parts to the whole that which defines all the possible geometries within the given interval of parameters involved. In terms of philosophy, it is not a particular because it is defined generically. That is to say, instead of drawing, making physical models –as architects have done for centuries- or even drawing and developing 3D models in the virtual space –as architects have been able to do in the past decades- architects can now codify their designs. As a result, the code generates a particular geometry but it is not the geometry itself because it is not fossilized into matter; moreover it is not defined geometrically but topologically [11, p. 86]:

A closed form (as found in a conventional design) is defined *geometrically* and necessarily belongs to a *metric space* because it is *material*. On the contrary, an *open form* (as a parametric or algorithmic design) is defined *topologically*, it is not contained in a *metric space* –instead, and to a certain extent, it inhabits a *topological space*-. Because it is a conceptual design it is not formalized into *matter*, rather it is a *logical construct* defined by a code, a *non material* language.

The levels of geometric complexity have dramatically increased thanks to parametric design (figs. 1, 2, 4, 9). As a result of generic form based design, strategies have shifted from form imposition to form finding and computers have begun to be considered as design partners rather than as simple and efficient tools. In addition, algorithmic architecture can introduce randomness as a design factor increasing the level of complexity achieved [12]. All this changes are only possible in the realm of *open form*. Taking into account that the idea of *openness* can be thought of as topological, a generic geometry can be defined in a topology; consequently *open form* could also be termed as *topological form*. Kolarevic [13, p. 13] has addressed

this issue writing “This quality of homeomorphism [the topologically isomorphic] is particularly interesting, as focus is on the relational structure of an object and not on its geometry –the same topological structure could be geometrically manifested in an infinite number of forms”. This collection of forms that share a common topological structure is what we have termed as *digital typology*, something that can only be achieved through the immateriality of a coded design.



**Fig. 2 Airspace Tokio, Thom Faulders Architecture 2007**  
(Photo by Thom Faulders Architecture)

The idea of open form as opposed to a more classical idea of finished design can be found in modern art. XIX century Symbolism was a first attempt to suggest different readings, considering the fact that a work of art is something produced by an individual that expresses thoughts, feelings, etc. and that can be interpreted by third parties in different ways. The more concerned about the idea of *reading* and *interpretation* the artist has been the greater degree of openness has been achieved. Nevertheless manifestations such as Calder's mobiles –perpetually changing geometries- introduce a wider degree of *openness* [14, p. 163]. However, it is probably in XX century music where we find explicit *openness*, such as in Stockhausen's *Klavierstück XI*, where the score is simply a group of musical phrases not arranged in any specific order and where the interpreter has to chose the order, the speed and the intensity to play the music [14, *Ibidem*] breaking with the idea of classic finished form and introducing randomness in the interpretation. In spite of all these different manifestations of open form, it must be agreed that parametric and algorithmic designs go as far as possible regarding *openness* in architecture. But it must be also clarified that any architectural design must have a formal structure and parametric or algorithmic designs do have a formal structure. All the possible formalizations based on a certain code generate a formal pedigree of shapes within

the range of parameters defined, all of which constitute a truly *digital typology*.

### 3 Complexity, Baroque and Arbitrariness

*Complexity* is at the core of digital culture. If there is something that has characterized the evolution of digital design ever since computer tools became irreplaceable it is *complexity*. In architectural design complexity has been greatly enhanced through the introduction of the virtual space and 3D modelling. Computer programs oriented to the generation and management of complex surfaces – such as Rhino- have greatly contributed to the freedom of form that these tools have provided the designer. Many of the complex geometries that have been achieved would have been impossible to design or to build without computers. Mitchell [15] has referred to architectural complexity as:

“...the number of design decisions relative to the scale of the project. We can measure it as the *ratio of added design content to added construction content*.”

Mitchell, thus, defines complexity as a function of what he calls design content and construction content. Design content can be understood as the number of design decisions involved in the development of a particular element in relation to its geometrical complexity whereas construction content is related to the number of construction inputs involved in the manufacturing process of that particular element. Thus, a more complex geometry will need a greater number of inputs or parameters necessary to define it. Similarly, a greater number of operations needed to produce a particular constructive element will result in a greater level of complexity. Gehry's Guggenheim Museum at Bilbao (fig. 3) has become a classical example of complexity in architecture. It has also become an icon of digital culture in architecture because it was the first relevant building to be not only designed but built with digital technologies and happened to be finished just at the very end of the XX century thus becoming a chronological inflection point for digital architecture. To be precise, it is only half digital since the conception of the building was rather conventional –sketches and physical models that were laser scanned to produce a digital model.

As it is easy to follow Gehry's Guggenheim fits the frame of complexity defined by Mitchell, it is geometrically complex –it requires an extraordinary number of parameters to define its geometry- and it is also very complex to build –it requires unusual precision in the placement, positioning and assembly of constructive elements-. This building epitomized the new possibilities of architectural language introduced through the use of C.A.D./C.A.M. techniques. Gehry had first used new technologies to develop and study the constructive viability of Disney Concert Hall project, however Bilbao's Guggenheim was finished first and has remained ever since as Ghery's *opus magna* although many of the research and development of the whole design process from inception to tender plans begun with Disney's Concert Hall. Iwamoto [16, p. 6] has referred to it on the following terms:

At that time the skin [of Disney's Concert Hall] was conceived as stone and glass, and the office successfully produced cut-stone mock-ups, using tool paths for computer controlled milling machines derived from digital surface models. In other words, the digital model was translated directly into physical production by using digitally driven machines that essentially sculpted the stone surface through the cutting away of material.

Gehry's designs show the possibilities that the use of the new C.A.D./C.A.M. technologies may entail. At the same time they show how an increasing baroque has been introduced through the use of these tools. Architectural complexity could only have been achieved through the use of these tools but, certainly, complexity should be an *effect* of site conditions, complex programs and cultural sophistication and not the *cause*. Modernist simplicity aesthetic has been confronted by this growing complexity as part of the *differentiation* process; but in architecture the *formally complex* should not be confused with the *geometrically complicated*. Complexity despite its countless elements and the intricacy of their composition is arranged according to a certain order that can be understood. A complicated geometry is more the result of lacking clarity of order and the whimsical authorial imposition of banal formalism over architectural form.



Fig. 3 Guggenheim Museum Bilbao, Frank Gehry, 1991-1997

In the debate whether architectural form is arbitrary or not Tafuri was probably the first to write on the arbitrariness of architecture regarding Piranesi's designs for Campo di Marzio: “The ruthless authority of the language is felt in an almost unbearable way by the person who discovers not only its arbitrariness but also its instability.” and goes on stating that Piranesi's Campo di Marzio represents “the absolute disintegration of formal order, of what remained of humanistic *Stimmung*, of its sacred and symbolic values.” [17]. Again, we find ourselves in a linguistic debate applied to architecture understood as a language, and what Tafuri himself referred to as “language's authority” meaning by it the absence of any symbolic values. Unlike postmodern historicism for whose classicist revivalism was an intellectual alibi linked to a semantic debate, modern architecture must be based on syntactical rules that refer to the object itself and not to any symbolic value embodied within. Moneo [18, pp.17-18] has referred to Tafuri's text adding “Piranesi tries to show the origin, terrifying and necessary, of an architecture that works

'beyond meaning, apart from any symbolic system and strange to architecture itself"<sup>1</sup>. Tafuri is attempting to show the arbitrariness of architectural design understood as writing, because Piranesi is defying the classical rules based on the organic conception of the whole and its eurhythmic relation to the parts that are ordered to form it. Instead, his artificial disposition and the highly contrastive geometries gather to challenge any established canon.



**Fig. 4 C\_Wall, Andrew Kudless/Matsys, 2006**  
(Photo by Andrew Kudless).

Eisenman has also referred to Tafuri's text and has introduced some convincing arguments to limit the linguistic extrapolations to architecture although partly agreeing with Tafuri's text. It is obvious that the sign, in a textual language, is arbitrary, being as it is a convention that varies from one language to another. Thus, two different words in different languages may however share the same meaning. In architecture a complete unmotivation of the sign is very difficult to achieve unless we separate the symbolic from the functional within a given element. Eisenman [19, p. 155] adds:

In one sense a zero degree of motivation in architecture is problematic because the internal structure of the sign is different from the linguistic sign. Since the column will always be the column in itself and the sign of the column, this condition can only be presented as unmotivated. The

becoming unmotivated of the architectural sign initially requires a separation of the column's structuring function and its sign function.

Thus, in architecture, where buildings must be sanctioned by the laws of physics, the different elements must have a constructive purpose. Of course, because there is a context of history and an architectural tradition those elements may attain, as in the case of the column, a symbolic meaning. However, buildings must be supported either by columns or by walls, and their proper and primary function is of constructive order. That is the very reason why Courdemoy or Milizia would insist in the untruthfulness of applied ornament denouncing their validity at the beginning of Enlightenment.

Nevertheless, in relation to architectural design and architectural form arbitrariness has further implications and is convenient not to confuse both. It is obvious that the constructive elements must be placed, shaped and dimensioned where, how and as much, respectively, as required. These requirements must suffice both: structural and constructive needs –which directly relate to physics, gravity, wind and any other loads that should be supported-, and functional needs.

Structural needs are certainly not arbitrary depending as they do on three variables: geometry, material performance and loads involved. Neither can be the elements disposed to satisfy them. However, functional needs refer to the habitability of architectural space. This space has to be designed according to site tensions and functional needs but the complexity inherent to such combination together with the multiplicity of formal solutions that satisfy both sets of requirements make it impossible to optimize the relation between form and function. Any architectural competition may well illustrate this thought: many of the different proposals are good pieces of architecture that are suitable for the stated requirements but not one of them is really alike. Sullivan's famous motto "Forms follows function" is as relevant as ever, but many different architectural designs may well suit a particular architectural need. It goes without saying that many more don't meet such requirements.

Eisenman himself has used this idea of the arbitrariness implicit in architectural form with his spacing strategies and the use of diagrams. He has described his recent design methodology in three phases: a first diagram that is a geometrical abstraction of program requirements and site tensions (as in conventional architecture), a second diagram which is imposed over the first and that has no architectural base, and a third step of *extraction* through spacing strategies and figure to figure relations. Eisenman has written regarding the second diagram [20]:

This second phase is probably the most difficult and perhaps the closest to the machinic. It requires the choice of an outside agent, an external diagram, almost a *deus ex machina*, which contains processes which when superposed with the first diagram will produce a blurring of the form/function and meaning/aesthetic relationships that seem to have produced the first diagram. Such a second diagram may or may not be immanent in either the first diagram or in the formal interiority of

<sup>1</sup> The translation from the Spanish text is by the author of this article.

architecture, but must contain a process which has the capacity to modify the first diagram.

Thus, Eisenman introduces apparent arbitrariness within the final design taking into consideration the *linguistic* implications implicit in architectural design. However, his second diagram, although being foreign to architecture, is always an ordered system. He admits having used diagrammatic notations of things such as DNA structures, liquid crystals or fractals, all of which are ordered patterns. By *blurring* [21] the first diagram –based on the architectural problem itself – with this second *deux ex machine*, he achieves a hybrid geometry which must be compatible with the first purely architectural diagram. Then, through spacing strategies, he only needs to *extract* the final geometry into the third dimension which is thus enriched with the extra-architectural pattern.

In spite of this apparent arbitrariness of architectural form computer tools have produced and functioned as a feedback for complexity. A certain exaltation of complexity has become a trend in recent architectural design. Many of which –specially related to parametric design- can be justified in as much most of them are graphic proposals modelled in the virtual space or rather small installations thus avoiding conventional structural problems in architecture. The banalization of form is ready to flourish when the constructive requirements characteristic to architecture must not be satisfied. However, there are examples of parametric designs that have solved the constructive needs when the architecture has been finally built.

There are also cases like Evan Douglass' "digital baroque" that are not only out of time or out of trend; they are simply as false as historicist Postmodernism but even worse: they copy models of the past but in the strictly ornamental. In doing so, he disregards a well established architectural tradition on the untruthfulness of applied ornament contemptuously ignoring Modernist tradition on the logic of the materials and how they should be worked. All his voluted geometries are banal anachronistic reproductions of baroque and rococo decorative verbiage condemned to a lack of originality. Hundreds of years, new technologies and new design tools cannot be wasted to reproduce not even the formal repertoire of classicism with its added signified –as in the case of the column- but the superficiality of the purely ornamental.

The enhanced design possibilities introduced through the use of computer tools in the field of architecture has lead to an explosion of new geometries and complex architectural forms. If uncritically unleashed architect's imagination may end in a banal formalism. Architects cannot obviate the functionality of their designs being as it is the cause of architecture itself. Neither can they ignore the constructability of their proposals. It is obvious that architecture must stand still but it should be also obvious that scaffolding a sinuous surface like in a stage show with conventional platforms is not architecturally acceptable, something that can be said of much of Gehry's recent work. Architectural coherence and sincerity requires an inner consistence between the supports and the supported just because its durability and conceptual consistency relies on a constructive logic. In architecture, forms must comprise both: have a meaning and shelter a function.

## 4 New Formal Abstraction and Digital Fabrication

New C.A.D. tools in combination with C.A.M. techniques have also made possible the beginning of a new formal abstraction. For the first time, architecture has gone further than painting or sculpture in the exploration of a new aesthetic of matter. Modernism was formally linked with early XX century avant-gardes; in fact some of architects were reputed artists within them. Theo van Doesburg or Oud in De Stijl, Le Corbusier in Purism (a rather personal interpretation of Synthetic Cubism) or Lissitzky and Chernikov in Constructivism, are only some notorious examples.



Fig. 5 P\_Wall, Andrew Kudless/Matsys, 2006  
(Photo by Andrew Kudless).

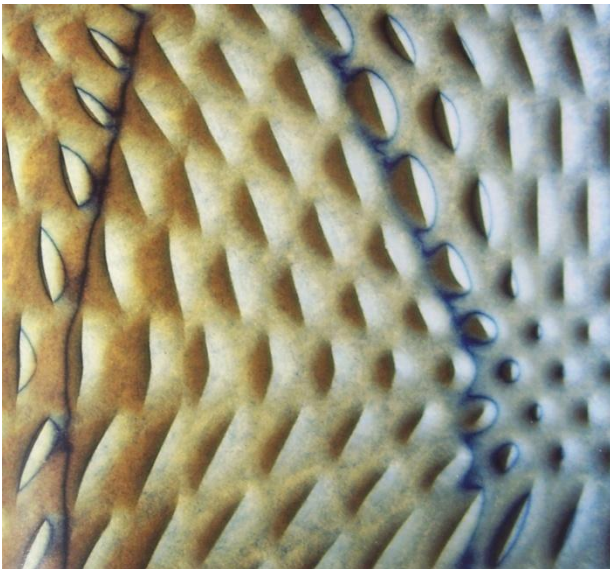
The advent of the virtual space thanks to computer based technologies has allowed conceiving and experimenting with extraordinary complex geometries. Thus, a new formal abstraction architecture borne has appeared thanks to computer modelling, an abstraction which is independent of XX century avant-gardes. In fact it is the increasing flexibility in the generation of surfaces on computer design programs that has opened the Pandoras' box of unimagined geometries. However, although the conception of these complex architectures can be achieved through C.A.D. tools, it is only making use of the synergies established between computer aided design and computer aided manufacture that these new possibilities are projected into materiality. Kolarevic [22, p. 6] has referred to these synergies on the following terms:

Three-dimensional digital modelling software based on NURBS (Non-Uniform Rational B-Splines), i.e. parametric curves and surfaces, has opened a universe of complex forms that were, until the appearance of CAD/CAM technologies, very difficult to conceive, develop and represent, let alone manufacture. A new formal universe in turn prompted a search for new tectonics that would make the new undulating, sinuous skins buildable (within reasonable budgets).

It is true that the main change in the architectural paradigm is a result of these new design capabilities, that is, from a conception point of view. Nevertheless, there is also a change with respect to materiality and construction. May be there are not new materials clearly distinct from those that the building industry has been using for the past century, as it occurred in Modernism with regard to its past architectural referents. But there is an incredible shift from construction to manufacturing, from building to assembling. C.A.M. has produced an extraordinary change regarding the fabrication of architecture and the strategies to cut, shape, connect and assemble construction materials. As Kolarevic [22, *ibidem*] himself relates, the building industry has been one of the latest to acquire the know-how in design to make use of three-dimensional modelling tools:

This formal ignorance of wider design trends also stems from yet another ignorance –the technological one– of three-dimensional digital modelling software that made the smooth curves easily attainable by industrial designers, who used them widely on everything from consumer products to airplanes.

These remarks, being truthful as they are, hide the fact that the new imaginary has been extraordinarily enriched by architects ever since they became aware of the possibilities these new tools had to offer. The new formal abstraction which we refer to here is in fact an outcome of architectural design produced by digitally conscious architects.



**Fig. 6 Tool-Hide, Ron Klein, 2006 (Photo by Ruy Klein).**

Beyond the aesthetic implications which are not to be discussed here, there is something really remarkable of this new architectural paradigm which we refer to and that brings together both, the conception and the new materiality of the architectural discourse. The fact that computing enables to manage complex systems and is equally efficient in mass production of customized elements at not real greater cost has changed the way architects address the materiality of their designs. This is solely characteristic of computer aided manufacturing and is, to a certain extent, an architectural quality related with the openness implicit in the arbitrariness of the

architectural form. Unlike industrial design, which relies on mass production of *type objects* that have been carefully designed, engineered and chain manufactured, architecture's uniqueness in every project –due mainly to arbitrariness of architectural form and site considerations– make each one of them singular. Thus, the possibility of customization is more easily to be found in architecture. Modulation is a classical strategy which Modernism enhanced because of its interest on the industrialization of architecture. But the real shift from construction to manufacturing has been accomplished in architecture through the combination of C.A.D./C.A.M. techniques.

The articulation of complex surfaces and the necessary tessellation of construction materials due to architecture's scale have produced a wide range of imaginative design and manufacturing strategies that would have been impossible to achieve without computer aided technologies. Something that was needed the very moment this kind of double curvature surfaces had to be built as it happened with Gehry's Guggenheim or Disney's Concert Hall. In relation to the latter Iwamoto [16, p.6] has written:

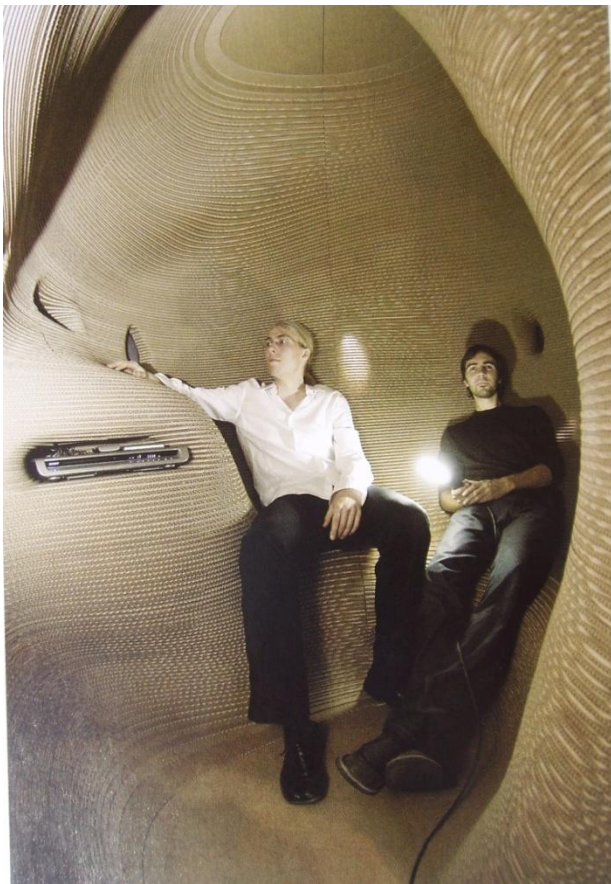
This building method revealed that the complexities and uniqueness of surface geometries did not significantly affect fabrication costs, and it is this realization, that one can make a series of unique pieces with nearly the same effort as it requires to mass-produce identical ones, that forms a significant aspect of the computer-aided manufacturing that has since been exploited for design effect.

## 5 New Materiality and Digital Fabrication

This new way of dealing with the constructability of architecture and its materiality has deeply changed architectural design. Mass production of singular elements that can be wisely articulated to build up a complex whole has led to what Cache [23] refers to as "the foundation for a non standard mode of production". Objects can be parameterized and calculated producing surfaces of variable curvature. Designs are, therefore, based on form-finding strategies where architects manipulate their coded designs to produce series of possible outputs that must be discarded or selected in as much they fulfil the design requirements and the performance they are expected to encompass.

The synergic benefits of using computer tools in design and manufacturing has been reflected on the architects' work that has increasingly grown interested in the manufacturing of built architecture. As a result of this attitude new specific design strategies have been developed to explore the possibilities that are to be exploited through a sensible use of these tools. Lisa Iwamoto has recently categorized these strategies into five different types: *sectioning*, *tessellating*, *folding*, *contouring* and *forming*; all of which are precisely *digital* strategies. Most of them refer to the articulation of the surface, but that is only logical since architectural space must be confined within material limits that are basically surfaces and membranes. Only folding can be found in

deconstruction but, after all, deconstruction in architecture was computer borne.



**Fig. 7 Mafoombey, Martti Kalliala, Esa Ruskeepää, 2005**  
(Photo by Timo Wright).

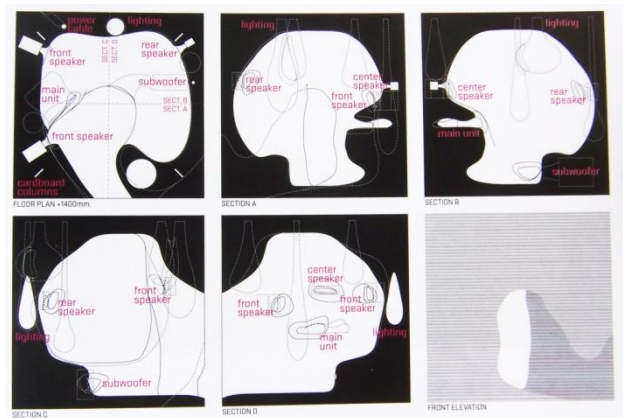
Sectioning is an equivalent of the conceptual methodology of infinitesimal calculus but instead of discretizing a curve the whole surface is cut into pieces by sets of parallel planes consequently becoming *ribs*. The ribs are then thickened according to the structural performance required, thus becoming material. Thus, a collection of ribs adequately near from each other will generate the complex surface (figs. 7, 8). Sectioning has been used in the ship industries for centuries: the structural frames that shape the ship's hull are a good example. The most remarkable thing is that it is also an operative method used in conventional two-dimensional projections to represent three-dimensional objects and this probably constitutes the genesis for digital sectioning in architecture. Here the process is inverted and through the two-dimensional cuts obtained by sectioning strategies the whole surface is generated through the integration of the discrete cuts. The CNC cutters play an essential role in the production of customized sections numerically controlled by the computers.

*Tessellating* operates as a performative strategy to articulate surfaces in ways that can be astonishingly decorative but at the same time truly constructive. (fig. 2). Picon [6 p. 141] has commented on such new ornamental quality of architectural surfaces:

From Basel Schaulager to the San Francisco De Young Museum, ornament becomes a pervasive surface condition, the variations of which are

based on levels of pixellization, a technique directly linked to the use of the computer to determine the grain of the materials employed.

Although tessellating has been practiced in architecture for thousands of years it is the new implementation through the use of computer aided design and manufacture that has unleashed architects' creativity to explore the possibilities of a new materiality. A materiality with unexpected textural and superficial qualities of architectural enclosures.



**Fig. 8 Mafoombey, Martti Kalliala, Esa Ruskeepää, 2005**  
*Program and equipment void diagram sections*

On the other hand, *folding* strategies can be traced since deconstruction. However, as it often happens with deleuzian theory in architecture, it is more the reading and the consequent interpretation that architects have made of it what has generated a *folding architecture*. The strategy of folding as has suggested Iwamoto [16, p. 62] "[...] is a powerful technique not only for making form but also for creating structure with geometry." (fig. 4).

The reason for its fitness within the architectural discourse has tectonic roots, for a folded plane in comparison with a flat one is strongly rigidized by the solely act of folding. The effective depth of the section of the folded plane in terms of structural resistance (the lever arm of the resistant section) is increased by the height or width –depending on a vertical or a horizontal positioning– of the fold. The consequence is a considerable increase in its resistance to perpendicular stresses and the momentum generated by them, something especially significant in the case of flexural stress. In addition to the tectonic consequences of folding this strategy also allows the formalization of irregularity within the structural. The calculus apparatus for structural resistance has been improved through the computers potential to deal with complexity; their suitability to emulate physical conditions and predict structural performance of complex structures through numerical methods in general and finite elements analysis in particular has allowed for the solution of parameterized designed complex geometries.

*Contouring* is a strategy related to carving materials; the technique is neither new and it is certainly not digital in its conception. Ever since the Greeks began to carve their columns certain profiles were contoured to work surface's textural values. Nevertheless, as it happens with tessellation or sectioning, it is the CNC routers and mills potential to precisely control paths which enhances this



design strategy to produce surprisingly superficial qualities on materials that are typically flat (figs. 1, 6). Materials such as plywood, stone slabs, cast composites or particleboards [16, p. 90], only to mention a few, are worked to obtain complex finishes that may customize each panel.

*Forming* explores the possibilities of moulding and assembly producing amazing effects. This *new materiality* that we have referred to is the result of applying digital techniques to digital fabrication exploring new possibilities that are inherent to the materials' own qualities, highlighted either through original combination of materials or through the way those materials are worked and finished. A good example of this strategy can be found in Andrew Kudless's P\_Wall (fig. 5), an installation for New York's MOMA. Iwamoto [16, p. 138] has described it on the following terms:

P\_Wall investigates the self-organization of two materials –plaster and elastic fabric –to produce evocative visual and acoustic effects. Inspired by the work of the Spanish architect Miguel Fisac and his experiments with flexible concrete formwork in the 1960s and '70s, P\_Wall attempts to continue this line of research and to add to it the ability to generate larger and more differentiated patterns.

The conceptual *openness* of parametric design has its parallel in mass-customization something that can only be achieved through C.A.M. and digital fabrication techniques. Complexity deals with systems of a great number of elements. It is the computers potential to manage these enormous amounts of data that enable mass production to be singularized, for example, in the tessellation of a double curvature surface. Thus the new design paradigm is complemented with digital fabrication customized manufacturing, an old dream come true. As Slenssor [24] has suggested:

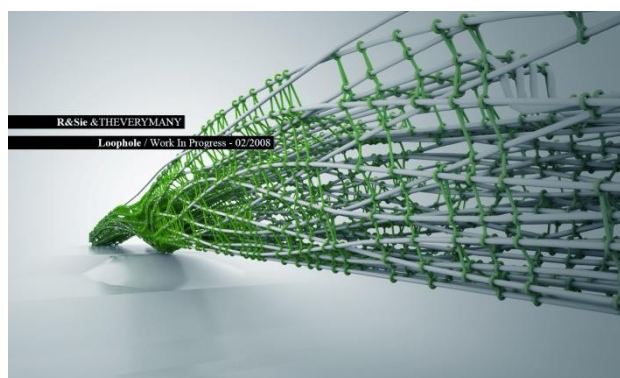
[...] the notion that uniqueness is now as economic and easy to achieve as repetition, challenges the simplifying assumptions of Modernism and suggests the potential of a new, post-industrial paradigm based on the enhanced, creative capabilities of electronics rather than mechanics.

The materials are basically the same as were during the modernist period, although some critics have begun to use the term *new materiality*. It is not necessary based on new materials –although there have been advances in this field too- but on the way they are, produced, manufactured and assembled. The combination of C.A.D. and C.A.M. technologies has brought together architectural design and construction engineering, conception and production, in a way that resembles much of the attributes of medieval master builders. Kolarevic [25,p. 57] has addressed this issue writing: "By integrating the design, analysis, manufacture and assembly of buildings around digital technologies, architects, engineers and builders have an opportunity to fundamentally redefine the relationships between conception and production.". Thus, it is the very complexity of digital architectural design that requires its integral consideration understood as a comprehensive process from inception to the finished building.

## 6 Conclusions

From the preceding exposition we can infer several conclusions which can summarize most of the issues digital architecture has put forward. Due to the extension limits of this paper, conclusions will simply be listed considering that the precedent text gives enough evidence of them:

- A new architectural paradigm has been achieved in digital architecture.
- This paradigm is based on both, new conception and new production standards.
- The idea of openness is at the base of the new architectural paradigm in varied senses.
- The new architectural canon is, in spite of its apparent contradiction, open but digitally conscious and based on processes of differentiation in terms of delezian theory.
- Digital typologies as a result of parametric design's openness are defined topologically instead of geometrically.
- Complexity as an inherent quality of computerized systems has become a common place in digital architecture.
- The arbitrariness of architectural form must not be confused with arbitrariness of architectural design and is related with openness and the impossibility to optimize form and function.
- A new formal abstraction architecture borne with no relation to XX century avant-gardes has been achieved within digital architecture.
- A new concept of materiality and materials has been coined to describe the experimental use of materials implemented through digital fabrication techniques.
- Architecture's consistency will rely, as always has done, on tectonic and constructive principles however explored in new ways through the synergies produced by computer aided architectural design and manufacture.



**Fig. 9 Loophole (w.i.progress), R&Sie&THEVERYMANY, 2008**  
(Image by Marc Fornes).

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opinions in the text are solely responsibility of the text's author and might not be shared by the authors of the proposals or built projects illustrated here.

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