New materiality: ideation, representation and digital fabrication

Carlos L. Marcos¹
¹Universidad de Alicante. Spain.
¹http://degraf.ua.es/en/
¹carlos.marcos@ua.es

Abstract. Digital fabrication has become the true counterpoint to computer aided design in architecture. Thanks to new C.A.D./C.A.M. technologies architectural design can now manufacture complex buildings that only a decade ago could have been almost impossible to develop. This convergence between C.A.D./C.A.M. technologies is producing a trend from construction to manufacturing. Arbitrariness of architectural form should not be confused with arbitrariness of architectural design, the latter being contradictory with the very essence of design. Conventional or digital architecture must achieve design consistency and must rely on architecture’s basic principle, that of necessity. New materiality is a term being coined in relation to digital fabrication and the way it should address materiality in architecture. Innovation in the use of conventional materials, the ways in which they may be manufactured or tiled, as well as the emergence of new materials may outline what new materiality is about.

Keywords. digital fabrication; new materiality; ideation; representation; open form.

REPRESENTATION AND DIGITAL FABRICATION SYMBIOSIS

Although digital tools have been with us for over 40 years, the acceleration in the changes they have introduced in our field of design has only been significantly manifested with the turn of the century. What only begun as a timid and somewhat eccentric incursion in our field has increasingly affected not only the way architects design architecture but most important, architectural language itself.

Traditionally, architects would draw and build physical models, increasing the level of detail involved at every step of the design. C.A.D. tools soon replaced these practices with the advent of virtual space. The possibility to edit the drawn model with the extraordinary enhancements that derive from it completely outdated traditional manual drawing. Three dimensional modeling replaced physical models as the plasticity of any virtual design is unmatched by any material manifestation. The structuring of information itself -layering, blocks, external references, etc.- together with computers potential to manage enormous amounts of data gave architects the possibility to deal with complexity in ways that had no precedent in the history of the discipline. It was their response to the increasing sophistication
of modern societies, the complexity of the architectural discourse and the possibilities that these tools entailed alone.

The enhancements that the use of C.A.D. tools have introduced has been extraordinary enriched through the synergies that have emerged from their combination with CA.M. tools. Kolarevic (2003b) has referred to this kind of digital symbiosis between representation and digital fabrication in terms of “digitally-based convergence of representation and production processes”. Consequently, the architect’s role has shifted and is increasingly more concerned with the process of manufacturing the materiality of the design itself. Digital fabrication naturally springs from digital design as it relies on the computers’ precision and their unmatched potential to manage complexity.

This digitally based convergence can go beyond a symbiotic relation. A typical action aimed at the representation of an architectural form such as sectioning can become a design strategy as Iwamoto (2009) has well suggested: “With computer modeling, deriving sections is no longer a necessarily two-dimensional exercise.” Thus, instead of using the section as a way to produce an orthographic projection of a three-dimensional object it can be used to do both: define the surface and build the structural ribs that support it (Figure 1). This is possible thanks to the mentioned digital convergence and the fact that the computer model defined in the virtual space embodies the information necessary to communicate with a cutting-robot that will produce the parts to be assembled regardless its geometrical complexity.

The traditional architectural standard of architectural design aimed to ensure the constructability of what has been projected is now, shifting from construction to manufacturing. The digital avant-garde architect’s central role is recovering the medieval precedent of the master builders and their interest on both: geometry and materials. Obviously, architects have always dealt with the process of designing architecture and its counterpart, the construction of its materiality on site. However, medieval tradition did not strictly separate ideation from construction; thus the authorship was diluted among the different parties involved in the whole process. It was probably during Renaissance that these two stages of the process were split into two; most likely, the drawing skills of architects of the epoch and their eagerness in relation to authorship recognition contributed to such separation. As Kolarevic (2003a) has argued, “it is debatable whether the drawings emerged in the building industry because of the need to separate design and construction or whether their introduction produced the present separation.”

The fact is that the digitally conscious architect may well step over the limitations of drawing to precisely define the complete set of information needed to build any complex geometry benefiting from the
convergence between representation and fabrication. Hence, the traditional limitations of “drawing what could be built and building what could be drawn” as suggested by Mitchell (2001) can be passed over. The extraordinary synergies produced by C.A.D./C.A.M. design have foreseen the consistent future that can be expected out of digital architecture as well as the surprisingly innovation that this new technologies and their pioneering use can achieve in our discipline.

TECHNOLOGICAL TRANSFER AND INITIAL DELAY

Complexity as a theme has been accomplished through the combination of C.A.D./C.A.M. tools. The challenge to make blobs constructible pieces of ravishing new architecture forced architects to direct their interests beyond the newly discovered potentials of digital ideation. Hence, they had to control not only the curvilinear geometries conceived in the virtual space but the means of production to build blobs.

The somehow traditionally reactionary building industry had to borrow technologies from industrial design, the shipbuilding or the aeronautic industries. The convergence between digital design and digital manufacture was accomplished years earlier in these more technological businesses. Just as the Eiffel tower or Paxton’s Crystal Palace borrowed the steel structured frame and the glass wall from the engineers’ repertoire, the use of CATIA by Gehry’s office could be considered an analogous technological transfer.

Several causes can be sorted to explain why architects have initially delayed the use of these new tools and made a consistent use of them. The fact that architecture is, to some extent, a powerful instrument of political propaganda and has traditionally served as a mirror of the empowerment of its promoters, has most likely contributed to such inertial fashion behaviour. The endless reinterpretation and reading of a glorious mythical past within the discipline, something which could be simplified in the term classicism, stands for the repetition strategies (Deleuze, 1968) to be found in the architectural debate for centuries. It is worth remembering that this reading had fortunately its last go with postmodern historicism, only some decades ago, although nowadays it is difficult to imagine; so deep has been the shift in the architectural paradigm.

Architects’ own cultural background and disciplinary referents were, at its best, based on modernist models. The aesthetic austerity and the sobriety in the management of form characteristic of the latter led to a preference for geometrical simplicity. A moderation that had its reasons in the use of the new materials (reinforced concrete and steel), a logic that addressed both: tectonics and materials, an explicit criticism of the classical repertoire and an aesthetic parallel with XX century avant-gardes.

In any case, their training at architecture schools in the “certainties of the Euclidean geometry” implied that “the emergence of curvilinear forms poses considerable difficulties” (Kolarevic, 2003b). Before the fashionable curvilinear surfaced architecture made its appearance with blobs -and was finally built at a large scale in the most characteristic digital architectural icon, Gehry’s Guggenheim in Bilbao- computers had transformed the architectural debate in what to became called deconstruction, most likely the counter postmodernist trend, being, as it was, the opposite to a repetitive attitude -differentiation as termed by Deleuze-. Many of such folding architecture can be understood as a critical reading of modernism; although it did not properly deny it, it can be thought of as a differentiation strategy worked over modernist principals invigorated through the use of computer tools; much of the work by Peter Eisenman in the late 80’s can serve to illustrate this assertion.

With conveniently tuned software -again Gehry’s office pioneered the customization of CATIA’s s.w. that would end in the development of Digital Project by Gehry’s Technologies in 2002 (Iwamoto, 2009)- architects would finally be able to unleash their imagination liberating themselves from any kind of representational limitation. In doing so, they would open the path to extraordinarily intricate
geometries; a realm of complexity that could not have been possible to achieve without the use of computers.

The delay of the architectural discipline in the integration of C.A.D.-C.A.M. techniques within their work frame has, however, been compensated through the innovation that has flourished ever since. The shift of design paradigm has been so great that even a new formal abstraction can be talked of as architecture borne.

ARBITRARINESS OF ARCHITECTURAL FORM AND DIGITAL BAROQUE

Unlike engineers, that have to solve deterministic problems (no matter how complex these may be), architects have to deal with complexity in various ways. The problem of architectural form is not only determined by tectonics or other objective performance causes. It also relates to the meaning of the architectural object and its contextualization within an architectural grammar. And what is normally most distinct from the engineers’ problematic: it is anchored to a site, the locus, a contextual reality. That is the reason why architecture can never be pure engineering and stands for a certain professional rivalry. We must then clarify why we should distinguish between the arbitrariness of architectural form and the logic of architectural design.

A ship’s hull can be engineered as a form that may optimize a certain amount of parameters. Consequently, the engineer can design it according to such dynamic and structural needs. As a result, most hulls have an extraordinary formal similitude, as they try to optimize a number of parameters that are basically related to hydrodynamics, resistance and a constructive logic characteristic of the shipbuilding industry; consequently they tend to attain a sort of type object configuration.

The contextualization of architectural form within architecture’s own discourse is one of the several aspects that make the work of architects rather distinct from that of engineers. Eisenman (2007) has addressed this issue on several occasions, in his architectural work as well as theoretically, stating: “the becoming unmotivated of the architectural sign initially requires a separation of the column’s structuring function and its sign function”. So as with the ship’s hull, the column will always be a structural element capable of supporting -basically- vertical loads. Contrasting with it, it will also be a syntactical element within architectural language, something that also interacts with a given heritage. Any column recalls a classical origin; its referential canonic precedent cannot be obviated: it can be criticized or it can be recalled, but it cannot be pretended to be considered as a new syntactical element. Obviously, depending on the material and the stresses involved its shape can be optimized structurally wise, just as the ship’s hull or any engineered element. However whether the column may be Ionic or a miesian cruciform steel pillar is a matter that transcends its tectonic justification: the column in itself cannot naturally attain a type object configuration as engineered objects tend to do.

Much on the contrary, architects cannot produce such typified forms; at least they no longer do. It is obvious that there is a typological history within architecture; gothic cathedrals, for example, were typologically developed and most of their evolution can be traced as a result of such typological conception. At that time, those buildings were very much like ships; consequently, the preoccupation for the consistency between geometry and tectonics was quite evident. The limitations regarding balanced loads over the bearing parts was greatly overcome centuries later with the improvement of structural calculus, on the one side, and the advent of steel and reinforced concrete, on the other side. Modernity obviated architectural tradition regarding such limitations and asymmetry soon became the evident compositional device to prove this emancipation. However, it was not until the development of structural analysis software based on finite elements that the liberation of any kind of compositional rhythmic constraint was truly achieved as can be found in the oblique supports group in Villa d’Ava, designed by Koolhaas.
There is still another reason why architectural form may be considered arbitrary despite architectural design cannot be regarded as arbitrary at all. Much of criticism casted on architecture relates to a confusion of both things. This other reason can be found in its functional program and the fact that different shapes can shelter the same function. Recently, addressing this issue, I wrote: “Structural needs are not arbitrary and 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” (Marcos 2011). This multiplicity of formal possibilities that can satisfy a given set of architectural needs makes architecture a discipline bound to both: the logic of tectonics and to the openness of a design that cannot be objectified. Something that is quite obvious when different proposals for the same architectural competition are critically observed. Many of them are correct architectural designs although they may differ very much from each other.

Thus, different architectural forms can serve to a same use, and it is difficult to decide which one in particular is better than the rest, provided a minimum of quality design. In this sense, architectural form is arbitrary. It is not the result of a deterministic problem, as can be found in other analogous disciplines. “Form does follow function”, as Sullivan stated long ago, but not only. It is the result of a great amount of data inputs that have to be solved in an architectural geometry.

However, architectural design cannot be arbitrary because it is founded on principles that cannot be altered: such as tectonics, functionality, durability, scale, constructability, or architectural language, only to mention a few. These principles transcend fashions or styles becoming invariants of architecture. As in the case of the column, the tectonics involved can be objectified so that the final design must meet such structural requirements. Consequently, reinforced concrete or steel used by modernist architecture changed architecture’s own grammar settling a new architectural canon (Miranda 2005). Nevertheless, the unmotivation of the architectural sign cannot be ignored. Hence, architectural form may be arbitrary in terms of the potentiality of different designs fulfilling program and site requirements, but must be consistent with the objectification of its tectonic and performance needs; moreover, it has to address the grammatical implications of being a language in itself.

It is quite obvious, as Picon (2010) has wittily pointed out, that Digital architecture cannot be thought of aside the digital culture stream; it belongs to its time and it is nourished by the same inputs. Complexity, accordingly, is not only a possibility because of the advance in the discipline, it is also the result of an increasingly complex world, with more and more sophisticated societies and an accelerating culture nurtured on an enrichment of cultural layering.

The tendency of digital designers to produce installations of unlimited geometrical complexity often obviates the problems involved in architecture with regard to material resistance and its relation with scale. New materiality must address the suitability for the use of materials and certain geometries. Considering the process of manufacturing and the qualities of each material, it should optimize the election of the material and its shape making use of computational potential for analysis. Architecture, as has always done, must rely on necessity and tectonics as much as architects must be conscious of the duality between such arbitrariness of architectural form and the necessary consistency of architectural design. The use of new geometries should not fool architects with a fashionable formalistic splendour that could end up being meaningless in terms of architectural language as such formal intricacy could be inconsistent with architecture’s tectonics or other performance requirements.
Digital architecture should neither recall any formal repertoire of architecture's past since that would result in revivalism, something that after postmodern historicism is simply unacceptable. Digital baroque, as it has been named, is simply an absurdity. Some of the recent formal investigations of architects as Evan Douglis cannot be further from what should be expected out of new technologies and their use in architecture. It is quite clear that the extraordinary control over form that C.A.D./C.A.M. tools entail can produce the finest work and finishes with CNC-milling robots as can be seen in Douglis’ Helioscope. However, it is more than doubtful that this kind of ornamental revival may have any sense from an architectural point of view representing, as it does, a reactionary reading of architecture. Digital culture can only look forward being, as it is, an avant-garde within architecture. The richness of the geometries that computer tools enable to manage should encourage architects and designers to explore new possibilities, not to try to emulate forms that have completely lost their meaning and their reason to be. What sense does it make to reproduce geometries that were a clear result of a handmade work carved out of materials like stone or wood executed two and a half centuries ago characteristic of the ancien regime with sophisticated CNC-milling robots working on foams and resins at the beginning of the XXI century for contemporary society?

FROM CONSTRUCTION TO MANUFACTURING
Certainly, digital culture in the field of architecture was incomplete until architects became aware of the synergies produced between the digital control over the geometry and its eventual digitally controlled manufacturing. Computers played a major role in the transformation of architectural language during the 80’s and most especially in the 90’s. The development of three-dimensional modeling completely changed the trends and shifted from deconstruction to blobby architecture or to the first materializations of digital architecture. Undoubtedly, Gehry’s Guggenheim in Bilbao stands alone with the general recognition for being the first large scale building to be constructed characteristic of digital architecture, even though it was only half-digital. The conception phase was conventionally designed with sketches and physical models (Colomina and Gehry, 2003); only when these were laser scanned a digital three-dimensional model was produced, the rest of the process onwards was carried out digitally.

Apart from the original complex geometries of the building, probably one of the most remarkable things of Gehry’s Guggenheim was the complexity involved in its construction. Not only the geometries of double curved surfaces had to be carefully designed and precisely defined, but because they had to be built, unlike blob architecture mostly paper or virtual architecture- C.A.M. techniques had to be used. That is the most important contribution Gehry has made in digital architecture. Once it became clear that the new realm of digital complexity -capable of being handled with C.A.D. tools from a design point of view- had its counterpoint in the use of C.A.M. tools, digital fabrication emerged as the natural materialization of bold digital architectural designs.

Digital fabrication has given architects the chance to build their digitally conscious architecture revealing a new world of possibilities in the uses of materials, finishes and what it is most important: their assembly. This is what we refer here to as the shift from construction to manufacturing. Obviously buildings are constructed but the way in which materials are being dealt with, and the increasing tendency to manufacture every single part of the building and assembly it on site is probably a result of dealing with enormously complex geometries and the intricacy of the formal designs (Figure 2). Most of this digital fabrication is dedicated up to date to facades, skins, membranes and panels. Consequently, if the complexity of the design affects not only the surface treatment of the facades and the paneling but becomes a factor in the overall design, it will entail a comprehensive digitally fabricated architecture.
Modulation and repetition was a compositional device characteristic to architecture throughout history until the advent of digital architecture. Construction relied on those compositional devices that simplified enormously the constructive process based, as they were, on regularity. Modernity brought with it asymmetry although as Hitchcock and Johnson (1932) anticipated as early as 1932, one of its ordering principles was regularity. Digital architecture, on the contrary, has brought irregularity: the informal. This architecture is possibly one of the best materializations of an apparent chaos; however, as chaos theory states, even chaos has a subjacent order.

An extraordinary complex geometry is full of irregularities; control over such irregularities not only affects the design, it requires C.A.M. techniques and total station positioning for assembly on site. In this sense, we can understand the shift introduced through digital fabrication of the informal complex geometries -pure manufacturing to materialize an architectural design- in comparison to classical or modern construction of regular geometries whose formal control does not require such sharpness and accuracy and may thus be, constructed on site instead of manufactured and assembled.

The idea of irregularity links digital designs with digital fabrication as it makes possible the manufacturing of customized singular elements, an architectural dream come true. The articulation of complex double curved surfaces or folding geometries has lead to the necessity to customize each of the panels that constitute the whole, something that would have been unimaginable without digital fabrication techniques (Figure 3). Iwamoto (2009) refers to the design of Gehry’s Disney Hall in relation to this: “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.” This customization of the manufactured tiling or any other parts to be digitally fabricated with CNC routing, cutting, laser cutting, etc. has really spurred the viability of complexity in terms of a new materiality.

Cecil Balmond is certainly one of the pioneers among those engineers that work for architecture to solve the tectonics of informality. This irregularity of form is quite similar to a lack of hierarchy, a general informality that confronts with classical modularity or even modernist regularity. Balmond (2002) has referred to this kind of geometric situations of the complex and irregular in the following terms: “As the effects are multiplied by extension or overlapping, surprising and ambiguous answers arise. Because there is no hierarchy, only interdependence, I call this template of ideas informal.”

Figure 2
C_Wall, Andrew Kudless/ Matsys, 2006 (Photo by Andrew Kudless)
NEW MATERIALITY, PARAMETRIC DESIGN AND DIGITAL FABRICATION

The term new materiality has been coined in relation to digital architecture and the way it can address the theme of materiality in the designs (Picon 2004). Conceptually, new materiality in the realm of digital architecture could be understood as the constructive logic intrinsic to materials and new fabrication methods. In spite of the enormous variety of digital architecture—a good example of how architects have assimilated the deleuzian discourse of difference and repetition—the truly digitally conscious architect should combine the mastery of the tools as well as the aim to understand the material implications of built architecture.

Because of the synergies that spring from digital design and digital fabrication, architects are bound to the inner logic of manufacture and assembly, of how their bold geometries can acquire materiality and become built realities. This recalls an ancient tradition in architecture, that of medieval master builders, as has noted Kolarevic. In fact, it also relates to Gropius' and the Bauhaus' pedagogic ideal of conceiving architecture as the discipline into which the medieval concern on the materials and the integration of the arts and crafts into a polyphonic work could be merged.

The characteristic concern about complexity on which digital culture in architecture was based from a design point of view has found in digital fabrication its counterpoint with the capability to manufacture customized designs. The possibility to digitally design and to mass produce singular elements such as tiling of irregular surfaces to build up a complex whole has given architects the potential to deal with complexity not only as an aesthetic reference or an ideological principle, but to manufacture and assemble complex buildings (Figure 3). This is what Cache (1995) has referred to as “the foundation for a non-standard mode of production”. The mechanic capacity of robots can now be used to mass produce not just regular elements but singular ones at hardly any greater cost.

However, the increased complexity that can be achieved with new design tools has often led to the banalization of form inconsistent with architecture's own tradition. A new materiality should articulate an architectural constructive logic as stated by Milizia in the XVIII century for new digital fabrication techniques, consistent with the fact that architecture is pure applied physics and is founded on necessity.

Regarding the idea of new materiality, a final conclusion could be its connection with the idea of emergence, which citing Picon (2010) is a property to be found in nature’s and in artificial designs: “Whitehead saw the world as founded on processes rather than substances. In such a perspective, that Kwinter and others like to characterize as a new and radical materialism, emergence appears as a fundamental property shared both by nature and design”.

New materials are being designed, and it is likely that some of them may soon become part of
the building industry. Extraordinary qualities can be achieved through the design of the inner structure. Materials with inner structural hierarchy can achieve, for example, negative Poisson’s ratio or enhanced structural performance (Lakes, 1993). Intelligent glass that is being developed at Cornell can be a spectacular platform to perform augmented reality features on surfaces, possibilities that now seem almost science fiction but that are already being manufactured and could soon become part of construction standards. This is yet to come, but it may well become part of the near future.

Parametric design has drastically changed the status of architectural design in as much as it has produced open designs or open forms (Figures 2, 3). The architect’s role has shifted from form imposing to form finding strategies. A parametric design generates a parameterized typology of forms within the range of parameters. The codification of the form may generate a debate in itself, but in connection to digital fabrication it opens the possibility of customized design and varied tiling in the definition of curvilinear surfaces. ‘Open form is possible thanks to abstract constructs such as parametric or algorithmic designs. Its definition is topological instead of geometrical; unlike conventional designs, it is non material.’ (Marcos 2010), something relevant as it connects architectural typology with the series of parallel designs emerging from a particular parametric design.

In relation to architectural ideation, Lisa Iwamoto (2009) has recently classified a whole series of digitally conscious design strategies: sectioning, tessellating, folding, contouring and forming. All of them involve a conception of form linked to how it is built, how it acquires materiality. Using Iwamoto’s own words “Digital fabrication, in particular, has spurred a design revolution, yielding a wealth of architectural invention and innovation”.

CONCLUSIONS
Open form introduces a new design paradigm in the context of architectural design since the control over form is parametric, hence codified and non material. Moreover, parametric designs define clear topological relationships between the parts of a particular design. Parametric design and digital fabrication -significantly customized mass production- enables architects to manage extraordinarily complex geometries. Digital fabrication can be also used as a quick way for prototyping and build reduced mock-ups. Architect’s initial technological delay in the use of C.A.D./C.A.M. tools has been balanced thanks to the boldness and the innovation that may be found in their recent designs. A new architecture-borne abstraction can be claimed to emerge from digital architectural designs. Digital fabrication has proved to be the ideal counterpoint to C.A.D., enabling the manufacture and assembly of complex designs that would have been unconceivable without those tools, but that would have been impossible to bring into the materiality of built architecture without the management of C.N.C. and milling robots. Arbitrariness of architectural form must not be confused with arbitrariness of architectural design as it relies on the idea of openness and the impossibility to optimize form and function. New materiality also refers to a wise use of materials according to their intrinsic qualities complemented with innovative ways to manufacture or to assemble conventional materials. Laying of bricks digitally positioned can, i.e., produce unexpected finishes and ways to work masonry. The pending challenge that digitally conscious architects must confront is the effort to design simplification instead of formal proliferation, having a good reason for every design decision or for any material use. Digital architecture will achieve its maturity when complexity is achieved as a result of initial design and site conditions, not just as an aesthetical or an ideological trend.

REFERENCES