

RIDING THE CLOUD. INFORMATION AND ARCHITECTURAL REPRESENTATION IN THE POST-DIGITAL AGE

Cabalgando la nube. Información y representación arquitectónica en la era post-digital

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ABSTRACT

The aim of this paper is an analysis of the evolution of the impact of information and communication technologies on the ideation, representation and construction of architecture. Since the origins of the so-called “digital turn” this issue has been the subject of extensive critical thinking and disciplinary debate and has now become an area of fully operative research which is necessary to achieve a comprehensive approach to the phenomenon by developing a theory of digital design.

The use of digital tools has produced substantial changes in architectural practice in the fields of graphic representation, information management and virtualization processes with a special impact on all aspects of graphic survey for cultural heritage study, research and conservation.

Along with new technological tools are new approaches such as “non-linearity”, the importance given to process instead of form shaping as reflected in the development of the BIM (Building Information Modelling) tools, the role of interactivity and performance or the concept of participatory authorship inherent in parametric design that challenge the traditional role of the designer which has been in force from “the Albertian code” and suggest a new agenda for architecture full of challenges in the era of the new media and collaborative design.

The paradigm shift from mechanical to digital technologies should be analyzed keeping a critical attitude toward the potential of the digital but at the same time, trying to see beyond the problems of formal aesthetics and framing it in the context of the history of cultural technologies.

Keywords

digital design, digital fabrication, parametric design, collaborative design.

1. INTRODUCTION

For the last three decades, a series of advances has come about in digital technology, which has resulted in the development of powerful visualization tools,

sophisticated systems of digital modelling and efficient structures of centralized databases. All of these advances allow radically new forms of coordination between the different agents of the edification project. The BIM systems, for example, provide a platform upon which digital construction and design information originating from different sources are able to intercommunicate and coordinate in an effective way with the added advantage that the digital management tools are capable of total integration with these systems.

Simultaneously, the impact of digital technologies in the ideation, representation and construction of architecture has led to deep critical reflection and has also generated a disciplinary debate, at times polemical, which can now be contemplated from a certain historical perspective, giving rise to a current ambience of vigorous research which is also necessary in the achievement of a complete approach with respect to an always complex phenomenon as is the role which technology plays in architecture.

Other technological advances such as wireless networks and technologies, RFID applications (Radio Frequency Identification), intelligent sensors, ubiquitous computing (also known as “cloud computing”), as well as digital measurement systems and the possibilities that Augmented Reality and 3D printing in combination with the already mentioned developments offer, make it possible to take full advantage of the new digital infrastructures within the context of the emerging concept of “intelligent technologies”, which is radically transforming the field of construction and architecture.

The adoption of new design patterns, along with collaborative work, produces not only an improvement in communication between the different agents with a subsequent reduction in errors and redundant information, but it also allows design “teams” to use the experience of practitioners from diverse “occupations” in a more significant way. The advantages in using the new tools are obvious: accuracy, precision, development of new manufacturing techniques, analysis of flow models, possibility of error detection, effective location of building elements, use of alternative materials and use of new

technologies with traditional materials, without overlooking experiments with the new materials obtained through scientific research in such fields as nanotechnology or biotechnology, as well as the development of new procedures in construction based on automation, like the use of applied robotics and *Rapid Building* techniques. In effect, the old rationalist idea of architecture seen as a “machine” which potentiates the industrialization of construction activity reappears.

From this perspective, the process is no longer purely linear, production forms an integral part of the design phase thereby facilitating the collaboration of all agents, users included, from the outset. It may be said therefore that we are witnessing the unfolding of a new paradigm which will lead to the formation of a “collective intelligence”, made possible by transference tools and the representation/visualization of information.

In fact, one of the fields in which the impact of digital technologies has had most importance is that of the architectural survey of cultural heritage, with a continuous evolution of architectural-archaeological documentation techniques based on image sensors (multi-image photogrammetry) and laser scanning (Terrestrial Laser Scanner) which has brought about greater precision and rigour, all of which has come about in tandem with a progressive reduction in the costs of tools used. The “point cloud” constitutes the most genuine resource of this kind, which along with the concept of “cloud computing”, representative of the range of computing services available through Internet, transforms into a thought-provoking metaphor of the ubiquity of digital technology applications in architecture. (1)

2. DIGITAL (R)EVOLUTION?

The term “revolution” has been commonly used alongside the adjective “digital” to express or define the change in paradigm that the introduction of the computer in the practice of the architectural and building disciplines has implied, especially in the fields of representation/visualization, information management and the application of the concept of virtuality. There is no doubt in relation to the change in architectural conceptualisation that computer aided design has meant, not unlike the repercussions of the introduction of linear perspective during the Renaissance, another example of potent cultural technology.

From its initial heroic introduction into the Anglo-Saxon academic world, (the initiative Paperless Studio, 1992, University of Columbia serves as an example), with the adoption in many cases of radical positions vis a vis the sceptical majority, the establishment of what might be called the pragmatic approach of natural acceptance of the new medium has come about: a kind of “third way”, which is both inclusive and non-dialectical.

The ability of the new computing tools to offer building forms of great complexity must also be mentioned. Algorithmic architecture and parametric design, which have led to the proposal of concepts such as that of “non-drawing”, (2) bring us face to face with the proliferation of innovative formal proposals, a phenomenon that is linked to the extraordinary development of connectivity and the network, transformed into an “infinite Borges style library”. (3)

Whatever the case, and the initial moment of fascination vis a vis such complexity having passed, we are currently facing a moment of acceptance, adaptation and settlement in which the intelligence of solutions predominates, all further conditioned by the coincidence with the traumatic phenomenon of the global economic crisis and its implications in the field of construction, which in many cases, implies the need to completely reinvent the means by which professional activity may be developed.

It is clear that we have moved from the use of the computer, within a purely mechanical or perspectival paradigm, towards a vision of digital technology as something more than simply a tool of representation. The so-called “digital paradigm”, characterized mainly by non-linearity, speed and the possibility of change and mutation has been implemented, to such a point that one could argue that the true paradigm of our time will be precisely “paradigm change”.

It could be argued that we are facing a new change in tendency, a second generation digital architecture which could even be defined as “post-digital”, in which the architect becomes the designer of systems and processes, along the lines already set out by some pioneers like Gordon Pask who considers “design as the control of control”. (4)

Given that digital technologies are radically transforming the way in which architecture is imagined, designed and manufactured or built, we can put forward a series of key questions: Is the digital age giving form to a new architecture? Is a significant redefinition of the role of different agents involved in the building process coming about? Will it lead to the emergence of a new way or ways of building? Could, what in parallel with some definitions of critical architectural theory we might call “advanced building”, come about? Can we be witnessing the end of the concept of architectural authorship implanted in the traditional sense since its invention by Renaissance humanism? Without forgetting that the instrumental impact of these technologies places us within a new theoretical framework which will require critical reflection.

The issue of information and everything related to its production, communication, implementation, monitoring and management in the field of construction, shifts, therefore, to the forefront of academic and professional

debate. With the integration of design, analysis, fabrication and assembly, made possible by the use of digital tools, the relationships between ideation and production can be completely redefined and, hence, the disciplines of architecture and engineering, the “design professions”, can be integrated into a combined digital and collaborative venture.

Therefore, the idea gains strength that one of the fundamental aspects of contemporary building is not the rediscovery of curves and complex shapes, in what could be called “digital neo-baroque”, but rather the ability/capacity to generate constructive information directly from design/ideation and the ability to transfer/direct it towards the new processes and techniques of design and digital production. (5)

Contemporary architecture is characterized by its ability to take advantage of the innovations offered by science and modern technology, as happens with the handling of complexity, the chaos theory and the advances in biotechnology and nanotechnology. This multidisciplinary approach is based precisely on the ability of computers to address the behaviour of dynamic systems and models. In the area of conceptualisation, non-Euclidean topological geometric spaces are being considered, as well as the application of kinetic and dynamic systems and the use of parametric and algorithmic design criteria, which are replacing the technological approaches of traditional architecture. (6)

Digital design processes appear, which are characterized by open and unpredictable transformations that introduce a principle of uncertainty and randomness. The generative and creative potential of digital media, along with the advances in digital manufacturing processes, developed primarily in the aerospace and automotive industries, opens up new dimensions in architectural design and the building field.

Finally, we should mention the recovery of the aim of personalizing production through the concept of “mass customization” allowed now by new digital manufacturing strategies, abandoning the search for standardization of modern functionalism and entering into a world of versions and nonstandard variations in which architecture as a cultural activity is recovered through the incorporation of the virtual as a conceptual development and the parametric as a projective technique. (7)

3. THE “DIGITAL TURN”

If, in the previous section, we made reference to the so-called “digital revolution”, a new concept is beginning to take shape in the field of theory: the formula “digital turn” (8); to designate the process of involving digital technologies in contemporary architecture, which extends roughly from the early nineties until the present day. At the same time, the need to develop a critical

theory of digital design in architecture that will enable adequate characterisation of this phenomenon, is being emphasised.

The beginnings of this “digital turn” in the early nineties are clearly linked with advances in electronic technologies, which meant a change in society, the economy, culture and even the daily lives of individuals.

The first phase, that of the pioneers of a “new frontier”, was heavily influenced by the idea that Virtual Reality and Cyberspace could represent a radical alternative to physical space, considering even the design of new electronic places, where the traditional brick and cement design of buildings would be replaced by bits.

Mario Carpo, historian of architectural theory, points out an interesting affinity between architectural postmodernism and digital design, in spite of the fact that virtually all of the first stars of the digital vanguard emerged from the angular fractures of deconstructivism.

The appearance of a new digital tectonics in the nineties was possible, in parallel with the development of a new generation of modelling software, allowing direct manipulation of curves on the screen by using graphics interfaces (vectors and control points). Two mathematical aspects of this environment have had lasting consequences in digital design approaches: the continuity of *splines* and the variability of curves within certain limits or parameters. These remain as characteristic reference points within digital architecture.

The idea of an open and parametric generic notation implies the possibility of an authorship that can be shared by multiple agents, from designers to final users. This is a phenomenon characterized by the absence of -isms or styles given that computers are neutral machines without aesthetic preferences, but which facilitate the construction of certain types of forms that were impossible to represent and materialize with conventional tools until now.

In this sense, Carpo’s affirmation that: “a meaningful building of the digital age is not just any building that was designed and built using digital tools: it is one that could not have been either designed or built without them”, (9) gains interest. This potential possibility of materialization explains the emergence of curved folds as a design strategy within the architectural debate of the time as a kind of mediation between the unity of postmodernist form and deconstructivist fragmentation.

The digital design current may even appear to be a continuation of deconstructivism by digital means, with the influence of “the fold theory” developed by Gilles Deleuze as its starting point, in which was posed an exegesis of Leibniz’s mathematics of continuity, calculus based on inflection points and parametric notation, an influence that reaches the world of design through technological interpretation of Bernard Cache’s “Objectile”.

Paradoxically the assumption of the “Deleuze Connection” brings an injection of unequivocally postmodern thought into the world of digital design. The modernity of calculus as a notation of variations formed part of the genuinely postmodern pattern of variability, complexity and fragmentation.

If, against modern standardization, the postmodernists had defended differentiation, variation and choice, digital technologies placed tools and techniques appropriate to this end in the hands of the designer, managing thereby to close a kind of technological loop. (10)

Systems theory, the sciences of complexity, the theory of self-organizing systems, together with theories relating to uncertainty, chaos, and morphogenetic metaphors that describe adequately the digital dialectic between code (genotype) and parametric variations (phenotype), introduced the concepts of “non-linearity” or “emergence” that adapted perfectly to the computer operating modes regarding emulation of nature and the powers of human thought.

These non-linear lines of thinking frequently make their appearance in mainstream digital design, sometimes with Nietzschean and Bergsonian connotations, assuming a vitalism that sustains a romantic and at times irrational approach. In the early days this meant a psychological notion of cyberspace and the immersive environments, a kind of “new age” tendency within the digital field, that transformed into a more technological and less “spiritual” notion with the arrival of the theories of “emergence” deriving from the so-called “sciences of complexity” during the early years of the new century.

Hence design practices experimenting with so-called “performative design” in a review of the anti-modern attitude of postmodernism (mass customization, anti-industrial attitude and non-standard approaches) arose. We can consider this attitude to be a result of the dual nature of digital design theory which came into being inextricably linked at the same time to “deconstructionism” on the one hand and “postmodernism” on the other.

The bursting of the “dot-com” bubble in conjunction with the attacks of September 11, 2001 marked the end of the period of technological optimism which had characterized the digital architecture of the 90s, but the fundamental theoretical principles were already defined and constant technological evolution has not substantially altered this general framework.

In the last phase of this process, the transition from the construction of form to the definition of process should be noted. This has been stimulated by the adoption of new information exchange and management software in construction, known by the generic name of BIM.

Together with this fact, a new definition and assessment of the concept of ornamentation, based on a new theoretical awareness of the aesthetic implications of formalism, should be mentioned.

The universal extension of the possibility of building complex geometries using digital construction is postulated in the “theory of parametricism” by Patrik Schumacher, who even attributes the category of new architectural style to it, affirming that it could “become the first worldwide unified style”. (11)

But perhaps the most significant development in the digital field is that which determined by the participatory turn, known generically as Web 2.0. Overcoming the differentiation between spaces and physical and virtual communities, hybridization processes and interactivity and sensitivity reflected in the design of electronically augmented space has become part of the technological arsenal of the most advanced architecture, although it is usually used in non-structural aspects (environmental control, lighting, movable wall elements etc.), but the concept of actual participation in design has not yet been generally assimilated and poses major problems.

While free and open-source software programs (FOSS) are widely used or the opportunities for collaborative work that the net offers are exploited, “open source” architectural design with notations that can be used and freely modified at will, has not yet become fully established, in spite of the fact that building and architecture have traditionally been participatory enterprises.

BIM software and the very idea of parametricism carry implicit within them the concept of “participatory authorship” and facilitate collaborative strategies in decision-making, although this aspect represents a direct threat to the model of individual authorship, which has characterized modern architecture for five centuries.

This threat regarding the traditional role of authorship, might well be generating a deep division within the design environment and the digital culture, which generally tend towards participative and collaborative models, a situation that could adversely affect the field of digital architecture, which would have entered upon a vicious circle of repetition, recapitulation and reviewing of ideas already outlined in the decade of the 90s, thereby losing its dominant role at the forefront of the digital vanguard.

As a reaction, the vision of the new post-digital phase encourages the exploration and search for new possibilities of experimentation and also, the need to put forward new research proposals, for example, the design of living materials for use in building, which is posed as a new twist to the technological hybridizations of the most advanced architecture. (12)

4. AUTHORSHIP IN THE “POST-DIGITAL” ERA

The use of the term “post-digital” (13) suggests several issues regarding the possible characterisation of the period. Firstly, we can reflect upon the fact that the use of digital tools and techniques is not so novel, if we bear in mind that the first practical developments of these technologies took place towards the end of the decade of the fifties of the last century.

At the same time, a certain assessment or critical judgement regarding their implementation is implied, when currently they are already completely familiar and integrated into most contemporary design practices.

It also makes reference to the fact that the frontiers between diverse and previously segregated disciplines can now be displaced and crossed with surprising and innovative results for all the areas involved, thereby ensuring that multidisciplinary and hybridization form two of the defining characteristics of the moment.

This is not a novelty, given that the use of concepts, rules, techniques, software and even metaphors, especially metaphors, from other disciplines such as genetics, biology, mathematics or philosophy has been a defining characteristic in the work of every digital pioneer in the field of architecture, transforming this technological and intellectual crossbreeding into a characteristic condition of the post-digital.

Following this line, once again we find in artistic experimentation one of the most prolific and dynamic fields of research and reflection, from which concepts and new approaches can be obtained, which are, in turn, fully transferrable to the field of architecture within the context of multidisciplinary and hybridization that characterizes the era.

In the words of the researcher and digital electronic music theorist John Richards, “what would characterize post-digital aesthetics is the ‘bastardization’ of technology. This consideration goes beyond the digital and involves forcing a system to a condition for which it was not intended or appropriating something for a purpose other than that for which it was originally designed”. (14)

This is consistent with the opportunistic use of software and code which “DIY” (Do-It-Yourself) strategies propose and which characterize a great deal of the most advanced and experimental architectural research through the reuse of digital and physical content. The possibility of working while using digital DIY strategies and the notion of heterogeneity, are key properties of the concept of the post-digital environment characterized by the simultaneity of change and permanence, separation and integration.

One of the precise advantages offered by the post-digital approach is the positive assessment of the

uncertainty and ambiguity of human experience for which, in order to accurately describe the resulting environment, more flexible metaphors than those based on binary logic are required.

Already, in an article of 1998, Nicholas Negroponte, founder and director of the MIT Media Lab affirmed: “Face it - the Digital Revolution is over”, (15) heralding a turnaround and inaugurating a stream of critical reflection regarding the evolution of the impact of digital technologies that would lead to amazing lines of development such as the consideration of a possible “aesthetics of error”. In this sense the failure of digital technology could provide starting points for obtaining fruitful results and products of interest by exploring new territories in search of new content, forcing experimentation beyond predefined functions and software applications. (16)

Along with these aesthetic considerations, reflection regarding the concept of authorship has become a key issue for a sector of critical theory of architecture in the field of post-digital culture.

Campo shows how the evolutionary process of object manufacture began with artisanal elaboration, handmade process, with the implications of the difference and variety of each object. Then came machine manufacture, using patterns, molds, stamps or matrixes, with the resulting equality between all objects from the same matrix, inaugurating the era of mass production and standardization, which would become crucial to modernity. Digital technology, however, adopts another method because of the fact that the abstract processing of information allows each digitally made object to be really unique, moreover, possible variations do not pose any additional cost to the process.

It can be said, therefore, that the new paradigm of digital variability connects current digital tools to the pre-industrial model of ideation and collaborative manufacturing, in line with the principles upheld by the participants in the “maker” movement, who design and produce their products with 3D printers. (17) The new digital fabrication techniques make way for the notion of a “digital craftsmanship” as a strategy to overcome the limitations of both the traditional artisanal framework as well as industrialized production. (18)

The new design and manufacturing strategies, in which we can find multidisciplinary teams simultaneously working on various digital files and different interfaces, represent a technological and cultural change which brings about significant consequences. Product customisation can be achieved at a low or inexistent cost and all agents in the process can be involved in both design and manufacture from the beginning.

This new trend of participation and “democratization” of design generates resistance among professionals who have always been characterized by their heightened

sense of control (even the very “control of control”). The distribution of authorship implies a new status quo, a new way of working that breaks with tradition and practices which had remained stable for centuries, since Leon Battista Alberti’s invention of the architectural design concept, based on the consideration that a building must be an identical copy of the architect’s design, and the theory of the separation between design and project implementation which would lead to the modern definition of the architect as author. (19)

Carpo refers to a type of authorship that he calls “generic” (20) and which he optimistically contemplates within the framework of participatory social movements arising out of the philosophy of free and open source software. A way of working that would connect with the way in which many of the great works of pre-Renaissance architecture were built, for example, the Gothic cathedrals.

On further reflection, he shows less optimism towards the attitude of the designers and their opposition to the modifying of a professional status culturally defined by Renaissance humanism and he emphatically states that digitalism, with its new forms of “diffuse” authorship could represent “the most formidable enemy that the architectural profession has faced since its modern origins back in fifteenth-century Florence”. (21)

5. MANIFEST PARAMETERS

Part of this new consideration of the responsibility of architectural work, which could be understood as an authentic crisis of disciplinary identity, is largely due to the success and spread of parametric and algorithmic design techniques.

The parametric approach allows the designer to define relationships between elements or groups of elements and to assign them values or expressions to organize and control these definitions. It is usually applied through a tridimensional program of computer aided design which has connectivity and interrelationship as its underlying principles. (22)

Parametric design, despite its apparent novelty, was actually one of the first operational concepts in the field of computer-aided design and had already been expounded by Ivan Sutherland in his famous doctoral thesis titled: “Sketchpad: A Man-machine Graphical Communications System” in 1963, which proposed the first graphical interface allowing the user to sketch with the computer and parametrically implement changes in design.

Nowadays, it has become a commonly used design tool in many different operations and with different constructive modelling techniques, geometric programming, structural optimization, environmental simulation, genetic algorithms and digital fabrication (23)

and is considered an operative utility in creative development .

In an age in which “isms” seemed to have disappeared and manifestos were considered a relic of the early avant-garde, Patrik Schumacher, architectural theorist and partner in Zaha Hadid Architects, presented his “Parametricist Manifesto” in 2008 to mark the eleventh edition of the Venetian Biennale. This can be considered as the official and formal birth of “parametricism” which is defined as “the great new style after Modernism”. (24) A new architectural style with its associated systems, which enables the generation of new urban and architectural models for organizing and articulating the increased complexity of “post-Fordist” contemporary society. An architectural style, understood as a research and design program, which gave rise to the new concept of Parametric Architecture.

Advances in digital design techniques with tools like “scripting” (such as MEL-Script or RhinoScript) and parametric modelling (such as Generative Components, developed by Bentley Systems Microstation or Digital Project, based on CATIA V5) allow total emphasis on differentiation and a sense of organized complexity that makes parametricism work in a similar way to natural systems, in which the forms are the result of forces that interact according to predetermined laws.

Schumacher formulates five principles in his manifesto (in keeping with classic twentieth century architectural theory) to characterize the new paradigm: the inter-linkage of subsystems, parametric accentuation, parametric figuration, parametric sensitivity, and finally parametric urbanism, which would integrate all of the above.

In contrast to the Modern Movement based on the concept of “space”, parametricism differentiates “fields” in a dynamic view of a changing reality based on trends, flows, gradients, in which deformation is seen as a structure of organised information. It seeks to establish new lines of logical reasoning which enable the organisation and articulation of the high level of dynamism and complexity of contemporary society.

Another issue to bear in mind is its inherent multidisciplinary nature, due to the confluence of technical and aesthetic variety, which gives great flexibility in the design process, which, in turn, becomes the collective task of a work team able to use diverse digital systems like constructive 3D modelling, geometric programming, topological optimization, environmental simulation, genetic algorithms and digital fabrication.

This necessarily implies the adoption of new attitudes in relation to the traditional logic of the architectural project given that the designer role is modified, passing from that of generating different forms to that of process editor through the definition of initial, starting point conditions and the creative selection of the final result.

6. CONCLUSIONS

Advances in digital design technologies and manufacturing have brought about a transformation in ways of thinking, designing and building architecture. The ability to digitally generate and analyse design information and use it directly to fabricate and construct buildings, redefines the existing relationship between conceptualisation and production. This modifies the traditional role of authorship and gives rise to the appearance of new synergies between architecture, engineering and construction due to the hybrid use of digital technologies at the frontiers between the different disciplines.

Furthermore, the post-digital era provides us with a new repertoire of constructed forms, a direct link between that which is designed and that which is finally built. This digitization of information which fuses and makes design and construction converge, allows greater control of the process in which all of the agents participate as a whole and collaboratively on the same digital processes, favouring thereby the phenomena of hybridisation and crossbreeding.

In this situation and following the fall from grace of the seductive promise of cyberspace and the calling into question of the revolutionary status of digital technology, we have no option but to “ride the cloud” like experienced horsemen in the midst of parametric storms crossing the digital dust clouds produced by millions of laser scans, ploughing through intricate matrix jungles abounding with exuberant algorithmic vegetation or ranging the labyrinthine structures of knowledge held at the heart of the net.

Within the evolution of cultural technologies, from the invention of the alphabet to the reign of the omnipresent binary code, our luck is to be witness a new landmark in the history of the ever fascinating relationship between both science and technology and architecture. If, as McLuhan affirmed, “first we build the tools and then they build us” perhaps the process of analysing the digital in architecture is in reality a process of introspection, of understanding how our way of viewing the world has changed under the influence of these tools, and, above all, how it has changed the way we see ourselves.

When all is said and done the problem is quite simple, it comes down to a question of ones and zeros..

7. REFERENCES

1. **Lerma, José Luis; Cabrelles, Miriam; Navarro, Santiago; Seguí, Ana Elena.** 2011. "La documentación patrimonial mediante sensores de imagen o de barrido láser", in **AAVV, Documentación gráfica del Patrimonio.** Madrid: Ed. Ministerio de Cultura, pp. 108-117.
2. **Marcos Alba, Carlos,** 2010, "Dibujo Parametrizado: un no-dibujo necesario en el EGA", in *Actas del XIII Congreso Internacional EGA. Vol. II.* Valencia: Editorial UPV, pp. 393-398.
3. **Fernández-Galiano, Luis.** 2009. "El diluvio digital" in *Revista Arquitectura Viva*, núm. 124, p. 3.
4. **Pask, Gordon.** 1969. "La significación arquitectónica de la cibernética", spanish versión in **Ortega, Lluís** (ed.). 2009. *La digitalización toma el mando.* Barcelona: Editorial Gustavo Gili, p. 27.
5. **Kolarevic, Branko,** 2003, "Information Master Builders", in **Kolarevic, Branko** (ed.), *Architecture in the Digital Age. Design and Manufacturing.* New York: Spon Press, p. 57.
6. **Sakamoto, Tomoko; Ferré, Albert,** (eds.). 2008. *From Control to Design. Parametric/Algorithmic Architecture.* Barcelona: Actar, p. 2-3.
7. **Ortega, Lluís** (ed.). op. cit., pp. 12-13.
8. **Carpo, Mario** (ed.). 2013. *The Digital Turn in Architecture 1992-2012.* London: John Wiley & Sons Ltd.
9. *Ibidem*, p. 8
10. *Ibidem*, p. 10.
11. **Hadid, Zaha; Schumacher, Patrik.** 2011. "Edificios adaptables", in *El País*, 22th Feb. Available from: <<http://elpais.com>>. [Accessed 16 February 2014].
12. **Spiller, Neil; Armstrong, Raquel** (eds.). 2011. *Protocell Architecture*, AD profile 210, AD 81 March_April.
13. **Roke, Rebecca.** 2009. *Bits and Pieces: Crafting Design in a Post-digital Age*, Master Thesis, School of Architecture and Design, RMIT University.
14. **Richards, John.** 2006. "32kg: Performance Systems for a Post-Digital Age". *Proceedings of the 2006 International Conference on New Interfaces for Musical Expression*, Paris, p. 283.
15. **Negroponte, Nicholas.** 1998. "Beyond Digital". *Wired*. Issue 6 (12). December, p. 288.
16. **Cascone, Kim.** 2000. "The Aesthetics of Failure: Post-Digital Tendencies in Contemporary Computer Music". *Computer Music Journal*, 24:4. Winter 2000. pp. 12-13.
17. **Anderson, Chris.** 2013. *Makers. La nueva revolución industrial.* Barcelona: Ediciones Urano.
18. **Bechthold, Martin,** 2012, "Customizing ceramics: digital craft", Lecture Summary in Qualicer'12. XII Global Forum on Ceramic Tile, 13th-14th February 2012. Castellón (Spain). Available from: <<http://2012.qualicer.org/documentacion/conferenciantes/resumen-conferencia-Bechthold-2011-english.pdf>>. [Accessed 16 February 2014]
19. **Carpo, Mario.** 2011. *The Alphabet and the Algorithm.* Cambridge, MA: The MIT Press, p. X.
20. **Carpo, Mario.** 2009. "Revolución 2.0. El fin de la autoría humanista". In *Revista Arquitectura Viva* 124, pp. 19-25.
21. **Carpo, Mario.** 2011. "Del alfabeto al algoritmo. Sobre la autoría digital y el diseño paramétrico". In *Arquitectura Viva* 140, p. 112.
22. **Dunn, Nick.** 2012. *Proyecto y construcción digital en arquitectura.* Barcelona: Art Blume, p. 54.
23. **García Alvarado, Rodrigo; Lyon Gottlieb, Arturo.** 2013. "Diseño paramétrico en Arquitectura; métodos, técnicas y aplicaciones". In *Arquisur Revista*, Año 3, Nº 3, pp. 17-27.
24. **Schumacher, Patrik.** 2008, *Parametricism as Style – Parametricist Manifesto*, Presented and discussed at the Dark Side Club, 11th Architecture Biennale, Venice 2008. Available at: <<http://www.patrikschumacher.com/Texts/Parametricism%20as%20Style.htm>> [Accessed 16 February 2014].