

The Material Modulation of Objects

“It is fruitless to define *that which is* the matter of things. Matter is what is ultimately in things. Matter is what is, but that nothing is.” Tristan Garcia

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Since the materialist interpretation of Gilles Deleuze’s work by Manuel DeLanda, the philosopher and author of *Intensive Science and Virtual Philosophy*, we saw raise the idea of a flat ontology, where all objects obtain an equal ontological status.¹ Suddenly, the hierarchical classification collapses in favour of an equality of “ontological dignity to each individuated thing”, as explained by Tristan Garcia.² Thus, “a cutting of acacia, a gene, a computer-generated image, a transplantable hand, a musical sample, a trademarked name, or a sexual service [are becoming] comparable things.”³ In this context, where the objects are now side by side, it still seems necessary to specify the terminology in order to develop a coherent discourse. First, we acknowledge an initial contrast between the non-material objects and material objects.⁴ Among the elements of the latter group, we dissociate the natural objects, those generated by growth and evolution, from the artificial objects, created by man. This paper will mainly focus on the designed and fabricated objects; so-called material-artificial objects. The distinction does not presuppose any superiority or inferiority in comparison to natural objects, or even to non-material objects, but rather serves to distinguish the objects on which the discipline of architecture is based.

RELATIONAL OBJECT VS NON-RELATIONAL OBJECT

From there, let us analyze the influence of such an ontological flattening on recent architectural theories, with a particular attention to the generative process behind the form and matter of the object. This last point will be the main element in our argument. An interesting debate is currently taking place between architects defending the idea of *relationism* and those advocating an object-oriented ontology (OOO).⁵ This ideological confrontation is intimately related to the theme of this conference, by numerous questions concerning the autonomy of the architectural object.

First, the *relationism* approach, arising mainly from an architectural interpretation of deleuzian philosophy, is interested in the generative processes underlying the object, such as flows, intensities and connections. The resulting projects are dependent to their relations with an almost exhaustive network that defines them. Architecture becomes informed;

either by the influence of contextual forces on soft bodies, or by a series of topological deformations, or even with parametric differentiation of components, in reaction to their immediate environment.⁶ On some occasions, the material parameter will be embedded in the equation, through a relation of intensity. This will lead to a performative architecture, often explained as a material system inspired by biological structures.⁷ The most extreme version of *relationism* has surfaced in recent years, with the infamous *parametricism* of Patrik Schumacher, who theorizes architecture as a communication system, where the latter would be the only entity to be considered fundamental.⁸

This “radically flat ontology [...] however, also a radically relational ontology” raises an issue, as stated by Graham Harman in *Objects and architecture* where “entities have no autonomous reality, but gain their reality from those other things with which they interrelate.”⁹ As if the object’s properties would be “vaporized into an infinitely interconnected empire.”¹⁰

In contrast, we find at the other end of the theoretical spectrum the object-oriented ontology, aiming above all that the “concrete entities again become a central philosophical problem.”¹¹ By rejecting the *correlationism* position, Quentin Meillassoux constructs a philosophy where objects can be addressed ‘in itself’ at the center of a metaphysical scheme which requires, on our part, to admit that they do not exist only in relation to us.¹² Thus begins a philosophical study of the existence of objects. Thereby, they earn an existential autonomy, and this brings a lot of questions concerning their relations with each other, with their context and with us. Graham Harman elaborates in detail, throughout many of his writings, a version of a hermetic ‘object’, by expressing a non-relation of things.¹³ In this model, the object acquires autonomy mainly by its formal singular design, but little is known about its material formation. For his part, Timothy Morton has a more nuanced argument, almost at the edge of *relationism*, with the concept of the *mesh*. It represents a kind of web without center or limits, through which all living and nonliving objects are interconnected.¹⁴ An analysis of this concept reveals that it is more akin to the idea of symbiosis rather than holism, as it first seems to be implied by its general definition.¹⁵ This can be explained by a weak connectivity between the elements of the mesh, meaning that the objects belong to a single horizontal network, which was originally defined as a flat ontology.¹⁶ It also implies that the elements in the mesh are interacting with some others, without necessarily being in relation to all others; an important distinction. That is how they act in symbiosis since the objects are not reduced solely to their relations, due to a mesh that supports some degree of separation and difference. Thus, in this variant of OOO, the object accidentally loses some autonomy, as explains Morton: “nothing exists all by itself, and so nothing is fully ‘itself’.”¹⁷

Like the majority of exchanges between philosophy and architecture, the influence of object-oriented ontology on architecture should mainly be at the level of a metaphor in the theoretical development of the project.¹⁸ However, its greatest benefit for our discipline is to refocus the research and design on the architectural object itself, whereas it is considered an autonomous element. Mark Foster Gage, architect and associate professor at Yale, will even suggest that this ontology is some kind of antidote to the various ailments that paralyze the architectural discipline today; like parametricism, economical and political pressure, sustainable necessities, etc.¹⁹ Whether one is skeptical or not with this statement, one is forced to admit that architecture can be predominately justified by its own existence, through a spatial and formal design of the architect, without being in a state of dependency with few key relations.²⁰

However, if we return to the central purpose of this paper, we should not isolate the work on the formal aspect of the object from its material characteristics and its context. The object has much to gain from a relation with its physical environment, in order to exchange information contributing to its material organization. A separation between form, matter and the immediate context, would be an unfortunate return to hylomorphism; an Aristotelian

doctrine where every being, individual, or object, is made up in complementary manner of a shape and a material. From the Greek *Hylé* (matter, wood) and *Morphé* (form), this concept puts in direct opposition form and matter; the first is active while the second is totally passive.²¹ The material would then be the indefinite receiver of a singular form, an idea initially enunciated by Plato in *Timaeus*, with the ‘fundamental wax’.²²

Although these two perspectives, *relationism* and OOO, seem difficult to reconcile, we intend to explore the theoretical potential of their thin intersection. In other words, we are asking if it is possible to design an architectural object that could demonstrate a formal autonomy by a non-relational design, and a material autonomy through a relation to its physical context? To answer this question we need to dig into the philosophy of matter and form, and eventually explore the potentials of new tools.

MODULATION

First, the French philosopher Gilbert Simondon developed the concept of modulation, in his doctoral thesis *L’individu et sa genèse physico-biologique*, throughout the revision of hylomorphism.²³ According to Simondon, there is a missing element at the center of this mechanism, an element that could characterize and revealed how form and matter interacts with each other in a specific operation:

“The hylomorphic scheme corresponds to the knowledge of a man who remains outside the workshop and consider only what enters and what comes out; to understand the true relation between form and matter, it is not enough to even enter the workshop and work with the craftsman: we would need to enter the mold itself to monitor the operation of material formation, taking place at various levels of physical reality.”²⁴

Simondon decides to address the lack of information of this ‘black box’ that represents hylomorphism, and introduces the energetic parameter of ‘force’ in the equation. With it, he establishes the conceptual core of the technical operation which gives rise to an object having form and matter. The result is an ‘interactive platform’ between the three components, what could eventually be referred to as a system.

Simondon will support its theoretical reflection using a concrete process; the production of clay bricks. With the use of *real* material, the brick can’t result from the application of an *idealized* parallelepiped form on clay, as stated by the hylomorphism with its *abstract* matters. There must be an “effective technical *operation* [that] institute a mediation between a given clay mass and this notion of the parallelepiped”.²⁵ The wooden mold will accomplish this task, not by imposing its form on the clay, but by bringing it to equilibrium. The mold will guide the material expansion, through a slow process of stabilization, and this is done by a force reaction between the solid walls of the mold and the malleable matter.²⁶ This process will continue until an equalization of forces at every point, leading to a uniform distribution of clay, where movement is no longer possible. To be precise, this can be described as a *material modulation*, rather than a usual molding because the mold does not form directly the clay, but it is the clay that fills the shape of the mold. Moreover, Deleuze provides a clarification on the difference between modulation and molding, wherein modulation admits a continuous variation of matter, from a steady state to another. As he explained, “modulate, it is to mold in a continuous and variable manner, but we could also say that molding is to modulate in a constant and finite manner, determined in time”.²⁷ The ‘in-between’, the energetic element between the mold and the clay, solves the problematic initially raised in hylomorphism:

“The relation between matter and form is not thus made between inert matter and form coming from the outside: there is an operation common to and at the same level of existence between matter and form; this common level of existence, is that of force, coming from an energy momentarily transported by the matter, but extracted from a state of

the total inter-elementary system of a superior dimension, and expressing individuated limitations.”²⁸

It is through this relation of force that form and matter are determined, and as emphasized by Pascal Chabot, “the relation is not mysterious” as implied by hylomorphism, “it is simply physics”.²⁹

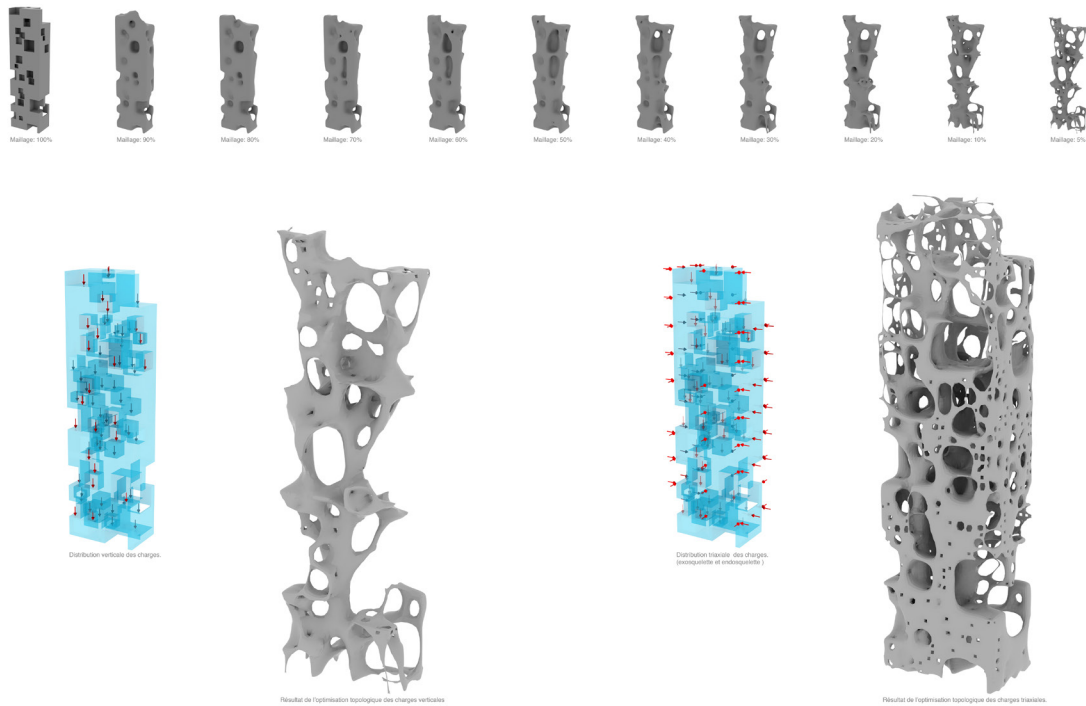
MODULATION OF DESIGNED OBJECT

We learn from Simondon that the relationship between form and matter is not an active / passive transmission as explained by the hylomorphism, or an autonomous form performing in isolation on the material like some version of OOO, nor an absolute relational exchange where entities have very little autonomy as described by parametricism. It is rather an energetic dialog between two equally active and autonomous components, namely form and matter. This last part is the most important in the context of this article, as we discover that the autonomy of the object emerges from both its form and its matter. Of course, these are two completely different types of autonomy. First, an intellectual or creative autonomy is assigned to the object by the design intentions of the architect. That is the formal and spatial characteristics that will define it, like the mold in Simondon’s example. Then, a physical or structural autonomy will be achieved by the stabilization of matter, in dialog with the designed shape; like the clay, which finds equilibrium in the mold.

Since form and matter must find equilibrium by modulation, Simondon explained that the object could persistently be in a state of becoming, bifurcating from a potential phase to another according to the multiples forces acting on it.³⁰ At this point, the relation between the object and its physical environment becomes crucial. The variations of force will trigger a phenomenon of metastability, which describes a far-from-equilibrium phase in thermodynamics.³¹ This means that if the object changes its form or even its context, matter should amend its internal organization accordingly. Such condition exceeds the simple idea of stability by considering the potential energy in the equation. The resulting asymmetric fluctuations of energy allow the system to adopt various structures over time, according to a multi-phase logic. Consequently, the object stabilizes when “the *good* form is no longer the simple form, nor the geometric shape, but rather a significant form that establishes a transductive order within a system of potential realities.”³² The metastable modulation eventually leads to a deletion of boundaries between form and matter, between the outside and inside of the object, between its composition and its constitution, as the first brings the other to equilibrium, and the second gives it a physical objectivity.

Let us now translate this concept of modulation in the process of architectural design. While the formal autonomy stems in a relatively linear way from the design intentions of the architect, the material autonomy by modulation is more arduous to reveal.

For that, we need to include material data in the design of an architectural object. Once this is accomplished, is matter becoming active? Does it produce a material modulation of object? As an answer, we suggest considering the algorithmic routines of topological optimization as a means of digitally generate the material formation. To express it succinctly, topological optimization is a method of calculation producing an optimal distribution of matter in space, with respect to its structural behaviours.³³ Through a continuous evolution of ‘structural shape’, this process attempts to maximize the performance of the structural system, while minimizing its weight.³⁴ From a theoretical perspective, topological optimization allows a precise understanding of material behavior, by a feedback between form, force and matter, and the generations of so-called optimal solutions, according to predefine constraints. The latter arise primarily from the relation between the object and its context, by the force of the immediate environment that will act on it. A digital simulation will evaluate the information to help determine the distribution of the material. The material becomes a flux, a “material-forces rather than [a] matter-form”, carrying its own



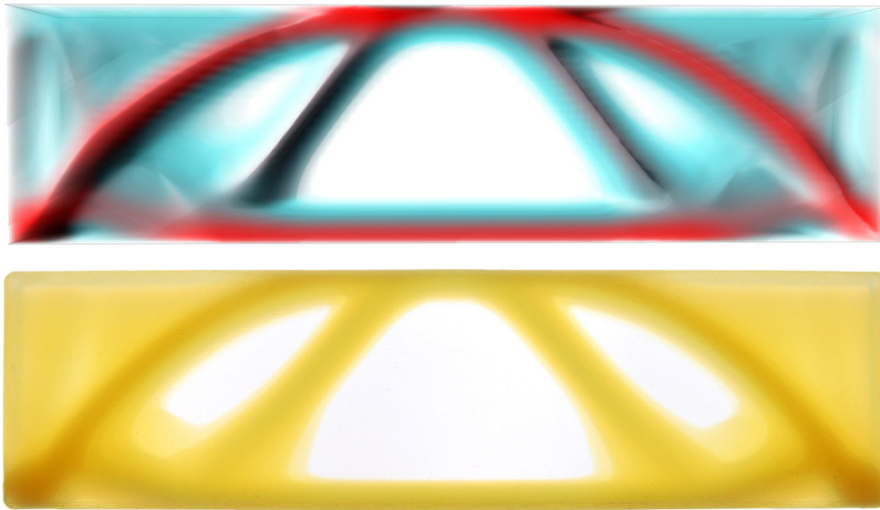
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Figure 1: *Topological optimization*;
 Pour une architecture de l'écume.
 Force, forme et matière dans la
 morphogenèse de l'architecture
 numérique (Ph.D. Thesis), Samuel
 Bernier-Lavigne, 2014.

singularities, like its strength, its elasticity, its porosity.³⁵ By an active and iterative reaction, matter solidifies the lines of force in space. Thus, we get a metastable system, dependent on variations of its environment that can trigger a bifurcation at any moment. Although some architectural theorists bring the idea that information would have killed the concept of structure, it is the opposite with topological optimization; this process will develop the structure directly from the information.³⁶

However, one must understand that the optimization algorithms don't usually have formal or manufacturing logic associated with their calculations. So, when used as the sole generative element of the object, they tend to impose a certain 'truth of the simulation' on its actualization. On the one hand, this ensure a certain material autonomy to the project; autonomy that is developed through a retroactive relation between the object and its environment. However, the hylomorphism is then reversed, with an active matter imposing its law on a passive form. This usually results in the generation of highly differentiated structures, exhibiting excessive topologies, reminiscent of some natural structures such as bone, trees, and others.³⁷ For us, the main interest of topological optimization does not lie in its ability to reproduce the natural processes, or even in generating a perfect structural optimization, often at the expense of other architectural parameters. We are rather interested in an objective understanding of matter under the effect of force, and to discern how this could truly inform the material autonomy of the object.³⁸

Although we are close to a solution regarding our original problem, there are still some links to be established. The main one would be: how to use topological optimization, and its active matter, while developing in parallel the formal autonomy of the object? We must project ourselves into the mold, as wished by Simondon, to monitor the operation that takes place between form, force and matter. It is important that the structure of the object could be capable of differentiation, recognizing the qualitative differences that only a matter subjected to force in its organization can demonstrate. From there, it seems clear that the architect must have a strong involvement in this process, by joining the design intentions to the results of the topological optimization.



2

NEW THEORIES, NEW TOOLS

Some new digital platforms will address this potential link between the formal and the material autonomy of the object. In general, they offer the opportunity to optimize the internal structure of a designed form. First, *Autodesk Within* introduces a structural lattice within the boundaries of the object, similar to the support structure found in 3D printing.³⁹ This lattice is then informed by a simulation of loads distribution and will modify its topology, mainly the dimensions of its members, in order to provide an optimal reaction to the physical stress. In this case, the aim is clear; reducing the weight of the designed object while maximizing its performance, without any interference on its form. However, this procedure gives rise to a complete separation between the outer form and the optimized matter inside. Thus, these two aspects demonstrate a certain degree of autonomy, besides being considered active, but are easily separable, leaving the object in a certain phase of incompleteness.

A second software, *Monolith*, will fill this deficiency by providing a voxel modeling engine.⁴⁰ Similarly to a pixel, which is the elemental unit of an image, and to a bit, which is the unit of information; a voxel is a volumetric pixel.⁴¹ Each voxel has its precise location in the three-dimensional volume that it forms, and may adopt different material properties. Unlike conventional modeling techniques, such as the Boundary Representation (B-rep) or surface modeling, voxel modeling creates an inseparable bond between form and matter in the design, considering that the shape is resulting from an aggregation of material voxels.⁴² Paired with the development of a new class of 3D printers that can print several types of resins at a time, it becomes conceivable to precisely program the formal composition and the material constitution of the object.⁴³ Each voxel may now have different material characteristics: flexibility, rigidity, transparency, opacity, or even a mixture of all that.⁴⁴ Since form and matter becomes the immediate result of a creative process, the influence of the designer on the object is almost absolute. Thus begins a new episode of 3d printing, leaving behind many years of formal prototyping, by incorporating gradual variations of matter, via what we could call a *digital modulation*.

When combining this modeling technique with topological optimization, which *Monolith* allows, each voxel becomes informed and can meet the exact structural requirements, by changing its constitution. This result in a material gradient inside the object, ranging from strong to weak organization, or even from rigid to flexible. It ultimately provides an optimized structure that meets the original design intentions. It also offers a viable solution to the main question of this paper, both in theory and in practice.

Figure 2: *Monolith*; Topology optimization and multi-material 3d printing, Model by Panagiotis Michalatos and Andy Payne, 2015.

ENDNOTES

1. Manuel Delanda, *Virtual Intensive Science and Virtual Philosophy* (New York: Continuum, 2002), p.41

Levi Bryant, *The Democracy of Objects* (Ann Arbor: Open Humanities Press, 2011), p.32.
2. Tristan Garcia, *Forme et objet ; un traité des choses* (Paris : Presses Universitaires de France, collection Métaphysiques, 2010), p.11, translation in: Tristan Garcia, *Form and Object; A Treatise on Things*, trans. Mark Allan Ohm and Jon Cogburn (Edinburg: Edinburg University Press, 2014), p.4.
3. *Ibid.*, p.1.
4. Graham Harman, *L'objet quadruple, une métaphysique des choses après Heidegger*, trans. Olivier Dubouclez (Paris : Presses Universitaires de France, collection Métaphysiques, 2010), p.60.
5. *Relationism* is a theoretical position that explains the condition of a system by its relation to the context. Many contemporary architects uses the term in reference to the projects of the first digital age, describing often "the notion that everything flows smoothly into everything else around it," see: Todd Gannon, Graham Harman, David Ruy and Tom Wiscombe, "The Object Turn: A Conversation," in: Cynthia Davidson (ed.), *LOG 33* (New York: Anyone Corporation, 2015), p.73-75.
6. Georges Teyssot and Samuel Bernier-Lavigne, "Forme et information : Chronique de l'architecture numérique," in : Alain Guiheux (ed.), *Action Architecture* (Paris : Édition de la Villette, 2011), pp.49-87.
7. The numerous research conducted at the *Institute for Computational Design* at the University of Stuttgart, by Achim Menges and his team, are at the forefront of this notion of performative architecture. See: <http://icd.uni-stuttgart.de>
8. Patrik Schumacher, *The Autopoiesis of Architecture, A New Framework for Architecture, Vol.1* (London: Wiley, 2011).

Many of Schumacher's inspirations are natural and material systems expressing flows and intensities. This usually results in a formal composition of the project, but on occasion, the morphogenetic process is also considered. Then, the material autonomy of the object takes a crucial place in the development of the project. See the work of the CO | DE group within the office of Zaha Hadid, and in particular, the experiments with physics simulation by Shajay Bhooshan (tutor at AADRL, [wework4her](http://wework4her.com)).

9. Patrik Schumacher, "Architecture's Next Ontological Innovation," in: Sarah Ruel-Bergeron (ed.), *Not Nature, Tarp – Architectural Manual* (New York: Pratt Institute, spring 2012), pp.100-107

Graham Harman, "Objets et Architecture, Objects and Architecture," in Marie-Ange Brayer and Frédéric Migayrou (eds.), *Naturaliser l'architecture naturalizing, Catalogue Archilab* (Orléans: Frac Centre, Éditions HYX, 2013), p.235.10.
Graham Harman, "Object Oriented Philosophy," in: Graham Harman, *Towards Speculative Realism, Essays and Lectures*, (Winchester: Zero Books, 2010), p.102.

CONCLUSION

The demonstration is then explicit; we can address simultaneously the formal and material autonomy of the architectural object, by catalyzing an active reaction of matter inside a designed shape. This is done with a theoretical reasoning, by Simondon's concept of modulation where there is a continuous energetic exchange between matter and form until they stabilizes accordingly. This is also performed in architectural design, with the use of new modeling tools that incorporates material data by the topological optimization process, which enables such a digital modulation. Thus, the idea defended in this paper finds itself at the intersection of a relational architecture and the object-oriented ontology, by a combination of concepts from the two approaches.

For those who are not involved in the digital movement, this process may seem to radically change the role of the architect. But for the digital designers, this alliance between formal and material autonomy, by giving a certain freedom of creation while using topological optimization and multi-materials 3d printers, seem to be one of the logical next step in the design of architectural objects.

11. Graham Harman, *Tool-Being, Heidegger and the Metaphysics of Objects* (Chicago: Open Court, 2002), p.49.
12. Quentin Meillassoux, *Après la finitude* (Paris: Éditions du Seuil, 2006), p.18-19: "By 'correlation' we mean the idea according to which we only ever have access to the correlation between thinking and being, and never to either term considered apart from the other. We will henceforth call correlationism any current of thought which maintains the unsurpassable character of the correlation so defined.", translation: Quentin Meillassoux, *After Finitude* (London: Continuum, 2010), p.13

Graham Harman, "Objets et Architecture, Objects and Architecture," op.cit., p.238

Ian Bogost, *Alien Phenomenology or What It's Like to Be a Thing* (Minneapolis: University of Minnesota Press, 2012), p.14.
13. Graham Harman, "Objets et Architecture, Objects and Architecture," op. cit., p.238.
14. Timothy Morton, *The Ecological Thought* (Cambridge: Harvard University Press, 2010), p.28.
15. *Ibid.*, p.33-35.
16. In contrast with *strong connectivity*, where all objects would be in contact with everything else. See: Graham Harman, "On the Mesh, the Strange Stranger, and the Hyperobjects : Morton's Ecological Ontology," in: Sarah Ruel-Bergeron (ed.), *Not Nature, Tarp – Architectural Manual*, op. cit., p.17.
17. Timothy Morton, *The Ecological Thought*, op. cit., p.15.
18. Philosophy must not become an instruction guide for the architect or being literally, and often naively, translated in architecture. See the discussion on this topic in: Todd Gannon, Graham Harman, David Ruy and Tom Wiscombe, "The Object Turn: A Conversation," op. cit. p.82-83.
19. Mark Foster Gage, "Killing Simplicity: Object-Oriented Philosophy In Architecture," in: Cynthia Davidson (ed.), *LOG 33*, op.cit., p.104.

This statement from Mark Gage is not surprising since he is one of the most fervent critics of parametricism. Gage had several discussions on this topic with Patrik Schumacher, through a series of articles published in *Fulcrum*, the AA's weekly free sheet, first in Issue 18 (Mark Foster Gage, "Project Mayhem") and the answer came the week after, in Issue 19 (Patrik Schumacher, "Convergence vs Fragmentation as Condition for Architecture's Societal Impact") in 2011.
20. *Idem.*
21. See: Centre National de Ressources Textuelles et Lexicales, <http://www.cnrtl.fr>
22. Platon (Texte établi et traduit par Luc Brisson), *Timée* (Paris: Flammarion, 1992), p.149-151. 23. Gilbert Simondon, *L'individu et sa genèse physico-biologique* (Ph.D. dissertation, 1957 ; Paris : Presses universitaires de France, 1964).
24. *Ibid.*, p.40, our translation.
25. *Ibid.*, p.29-31, translation in: Taylor Adkins, "Simondon and the Physico-Biological Genesis of the Individual," see: <https://fractalontology.wordpress.com/2007/10/03/translation-simondon-and-the-physico-biological-genesis-of-the-individual/>
26. For an interesting discussion on what constitutes the limit of an object, see: Tristan Garcia, *Forme et objet ; un traité des choses*, op.cit., p.146-148.
27. "Les cours de Gilles Deleuze, Anti Œdipe et Mille Plateaux: Métal, métallurgie, musique, Husserl, Simondon (27/02/1979)," Gilles Deleuze, accessed April 2, 2015, www.webdeleuze.com.
28. Gilbert Simondon, *L'individu et sa genèse physico-biologique*, op.cit., p.34, , translation in: Taylor Adkins, "Simondon and the Physico-Biological Genesis of the Individual," op.cit.
29. Pascal Chabot, *La philosophie de Simondon* (Paris: Vrin, 2003), p.77.
30. This statement is true as long as we remain in the design phase. Once the artificial object is actualized, it congeals the possibilities of organization, and the object starts a slow entropic decline.
31. Gilbert Simondon, *L'individu et sa genèse physico-biologique*, op.cit., p.6.
32. *Ibid.*, p.23.
33. Panagiotis Michalatos and Sawako Kajijima, "Intuitive Material Distribution," in: George Legendre (ed.), *Mathematics of Space* (London: Wiley, 2011: Architectural Design vol.72, no.4), p.69.
34. Per Dombernowsky and Asbjorn Sondergaard, "Three-dimensional Topology Optimisation in Architectural and Structural Design of Concrete Structures," in: Alberto Domingo and Carlos Lazaro (eds.), *Proceedings of the International Association for Shell and Spatial Structures (IASS), Symposium: Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures* (Valencia: 2009), p.1067.
35. Gilles Deleuze et Félix Guattari, *Mille plateaux, capitalisme et schizophrénie 2* (Paris: Éditions de minuit, 1980), p.458.
36. Ph.D. seminar taught by Antoine Picon, *Architecture et culture constructive: de la structure à l'ornement & Pour une histoire culturelle de la construction*, École Polytechnique Fédérale de Lausanne (EPFL), Novembre 2012.
37. See: *The Bone Furniture* from Joris Laarman (<http://www.jorislaarman.com/bone-furniture.html>), and *The Qatar National Convention Center* from Arata Isozaki, opened in 2011, (<http://www.archdaily.com/425521/qatar-national-convention-centre-arata-izozaki>).
38. Lorraine Daston and Peter Galison, *Objectivity* (New York: Zone Books, 2007).

39. Software released in July 2015. See: <http://www.autodesk.com/products/within/overview>.
40. Software developed by Panagiotis Michalatos (architect and assistant professor in architecture at the Harvard Graduate School of Design) and Andrew O. Payne, Ph.D. (architect and Senior Building Information Specialist at CASE). See: <http://www.monolith.zone>.
41. Hod Lipson and Melba Kurman, *Fabricated; the New World of 3D Printing* (Indianapolis: Wiley, 2013), p.277.
42. <http://www.monolith.zone>.
43. This capacity is possible by their many print heads and by mixing digitally these resins before spreading them on the building platform. These printers are the Objet Connex. See: <http://www.stratasys.com/3d-printers/design-series/connex-systems>.
44. Neri Oxman, *Material-based Design Computation* (Ph.D. dissertation, Cambridge: MIT, 2010), p.44.