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CONSTRUCTION OF DESIGN & DESIGN OF CONSTRUCTION

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Abstract **- Nowadays, we are working in a stimulating scenario where the new digital technologies and the traditional design process in Architecture are definitively mixed together. We know that majority of mistakes in the phase of construction comes from the design phase and this trend looks often to come from a base concept aimed to separate, dramatically, the design activity from the construction activity. The most negative effects were detected in terms of increasing costs and of decreasing of the quality of the buildings. The new computational methodologies can enable us to obtain significant benefits in reducing the gap between designing and building. The new parametric approaches can help to highlight the centrality of the constructive detail. The concept of parameter is, at the same time, logical element and material element; therefore its nature is related to the theory and also to the practice of the Architecture. If we think to the importance of the executive detail, the parametric approach looks like the link between the "bit" and the brick. It is necessary designing the building, according its constructive logic: that is possible only trying to develop a biunique link between the two phases of the process that must be conceived as only one. To think via parametric the constructive details, means knowing that any existing design complexity can be lead back to an original constructive element: this dynamic discloses the sense of the complexity. I think that the digital fabrication represents the first real "bridge" between design and construction, because transforms a digital component in real component. The new technical and cognitive paradigms can be an efficient contribution in order to define a theoretical and practical vision in order to understand "the design of the construction" and "the construction of the design" as one. The next step of that current research will be how to move our vision from the "Architecture as ontology" to the "Architecture as taxonomy".**

Index Terms**—Architecture; design; construction; cognition; details.**

I. INTRODUCTION

The Architecture should be originated from the needs of the people and it should improve the quality of the life of the final users. To obtain these goals, in the current time of crisis, can we still work in the "traditional" way, or should we change our habits in order to understand new perspectives?

New technologies are constantly provoking and raising many potentials, challenges and arguments in academia, practice, and even in the theory of architecture itself.

We have the possibility to rethink, critically, the traditional technique and culture of the design and the construction as well. How can we develop our own ways of benefiting from the new technology that cater to our environment? *"Little observation and much reasoning lead to error, much observation and a little reasoning to truth".* (Alexis Carrell, 1873 – 1944, surgeon, biologist and physiologist French Nobel Prize for Medicine and Physiology in 1912). We can use this provocative sentence to investigate every object of research and knowledge. In the research field about the relation between design and construction, we are observing often the risk of considering the phase of design and the phase of construction as independent of each other, or at most as two "watertight" compartments.

Therefore, we know how the gap between what we design and what we built, causes often a increase of costs, less quality of the buildings and longer delivery times. Nowadays, we are working in a stimulating scenario where the new digital technologies and the traditional process-product of the Architecture are definitively mixed together.

If we consider the concept of modeling and simulation, we can transform the constructive elements in digital object oriented therefore it is possible to obtain a strong ontological link between the digital design and the real construction of the same building.

II. NEW PROCEDURES IN DESIGN AND CONSTRUCTION

Thanks the increase of the digital technologies, new opportunities are continuing available for designers in architecture. Generally speaking, designers are addressing the

message of the digital innovation towards an aesthetic fashion that push people to identify "tout court" the new technologies with the possibility to build complex architectural shapes. Obviously, was impossible to conceive before the current amazing buildings, designed i.e. according with the new aesthetic of the algorithmic architecture; but the huge possibility to obtain free form, it isn't the most important value of the computational resource. Nowadays, in fact, we are able to control the process-product in the field of construction as never it was possible before; we can obtain more quality and less costs in the design-construction world.

In Architecture a recent trend is developed from the upgrade of the concept of "parameter" as core of new procedures followed by the designers from the original idea to the end of the life cycle of the buildings. Please note that on the one hand the message of the architectural opera was forever related to the lecture and to the understanding of its parts; on the other hand the concept of parameter is based on the meaning of relation. As most important consequence we can observe that the parametric approach to the design is located in the heart of the architecture. Any architectural part and any constructive components necessary to build it can be identified using specific parameters. The identification of any object, can be conduct from the first phase of the process-product to the last one; this procedure has both aspects: logical and physical.

The logical aspect concerns the possibility to set and to control the develop of the design, the physical aspect concerns the realization of the construction. Some new approaches to the design field are showing how is easy to generate an information model of the building and how is possible to manage it. In addition we know well how the parametric procedure in the design can become real, thanks to the high level of precision that the fabricators can offer today, working using the 3D printing procedure.

III. The Design of the Construction

There are several definitions of Architecture that are accorded with the different international technical and cultural backgrounds; researchers and professionals are working worldwide, to define the formalization of the current phase of the Architecture and its related key concepts [1]. Nowadays, what looks like definitely new is the concept of the new digital computation and the concept of digital computation implies a development of the concept of connection: not only between numerical entities but, also, between the actors and the phase of the project.

In the field of Architecture, the technology innovation, has always affected, not just the basic concept like space [2] but, also, the link between the design and the construction: the idea of the architect and how to build it. How to build a building means how design its construction.

The realization of a building it looks like a one way from the phase of the design to the phase of the construction. Shortly, we design how building. This theoretical direction is dramatically reinforced by two important factors.

The generative approach to the Architecture and the possibilities of the 3D printing in the fabrication. So, the gap between the idea of the designer and its fabrication has become so short.

"Contemporary architecture after the age of "Blob" seems to be more precise about these subjects. Architectural design is being affected by potentials of algorithmic computational geometries with multiple hierarchies and high level of complexity Designing and modelling free-form surfaces and curves as building elements which are associated with different components and have multiple patterns is not an easy job to do with traditional methods. This is the power of algorithms and scripts which are forward pushing the limits. It is obvious that even to think about a complex geometry, we need appropriate tools, especially software, which are capable of simulating these geometries and controlling their properties. As a result, architects feel interested to use Swarms or Cellular Automata or Genetic Algorithms to generate algorithmic designs and go beyond the current pallet of available forms and spaces. The horizon is a full catalogue of complexity and multiplicity that combines creativity and ambition together"[3].

"Designing the construction" is the final object of the attention of the actors involved in the design-construction process (Fig. 1).

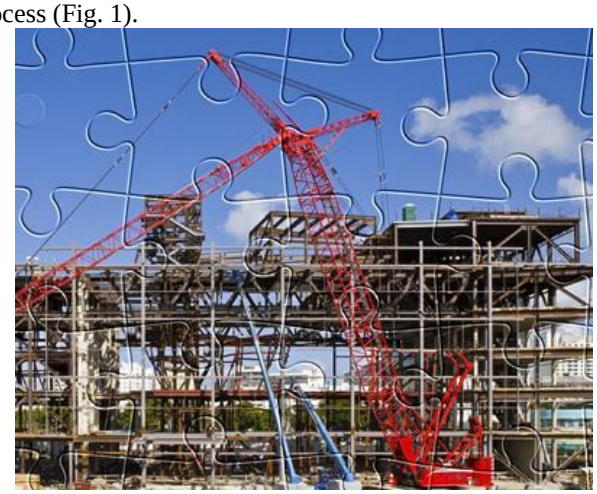

Fig. 1. **"Design of the Construction"**

The generative Architecture is born from the power of the digital computation, applied to the variation of the parameters, decided by the designers without knowing, in advanced, the final result of the computation. This procedure emphasizes the concept that we design the construction. However, a large part of the current architectural opera is pushing people to think that the new computational approach is identifiable with the complex architectural shapes built everywhere around the world, as the allegoric Flame Tower, built in Baku (Fig 2).

Fig. 2. **Flame Towers, Baku, Azerbaijan, HOK International, 2012**

Please note, instead, that it is necessary avoid this identification, in order to understand more deeply the meaning of the current possibility to obtain a "correspondence" between the Architecture designed and the Architecture built.

In fact if we consider the normal way of thinking the design activity we understand that it is oriented to represent the idea of the architectural opera. Therefore, the actors of the process are focused on the design of the construction just in a separated manner. This "separated manner", causes often a implied prevalence of the aesthetic value, with respect to the others aspects. From a theoretic point of view, the consequence is to give different relevance to the various disciplines involved in design of the opera.

But, nowadays, the activity of design becomes more and more complex due to the continuing developing of several factors: the costs, the specializations of the actors involved in the process, innovative materials and components more sophisticated , new laws and specific rules, the need of saving energy and the respect of the natural resources.

This situation push to rethink the link between design and construction because we need a more efficient way to design and to built our architecture according the needs of our time.

IV. The Construction of the Design

If the design activity must change in which direction can and must this change happen?

The starting point is that the design phase must to be rethought according the more complex scenario of the current world of constructions.

That means to be able to balance, definitively, the several aspects involved in the design-construction activities: so, the traditional approach based on the different value gave to the different disciplines, looks like not be more the reasonable way of working. In addition, the sequential approach between the several phases of the process becomes, often, unsuitable.

"Two features distinguish construction projects from many routine work processes. First, construction projects are typically unique in terms of the final products and the parties who are involved in the project. They are also often unique in terms of the physical and socio-economic environment they are embedded in. These factors increase the variability from project to project and increases the complexity of the project management and control in construction. Second, construction projects are complex in terms of the number of the activities and parties that are involved in the project and their interactions. Typically over 1000 activities are involved in a medium size construction project, which can increase the unpredictability of project schedule and planning. Uncertainty propagates in a project as each activity is influenced by/influences other upstream and downstream activities, i.e. predecessors and successors" [4]. In practice, we well know that only during the construction, can emerge several errors implied in the design phase, that was impossible "to discover" before. Worldwide, the majority of mistakes in the phase of construction come from the phase of design.

There are several reasons causing these happenings, beginning from the ontological level of the objects used in the design. In fact can be some conflicts between the different ways to conceive the same object by the different actors.

A wall, i.e., has a different meaning and a different value due to the different meaning gave to it from different actors (architects, structural engineers, mechanical engineers, interior designers) into them vision of the common project. (architects, structural engineers, mechanical engineers, interior designers) into them vision of the common project.

A partition of the plant, a structure that holds up the loads, a space where put the systems, a surface for a colour treatment... generally speaking each actor explores the design from his own point of view; therefore, a sequential vision of the entire design is generated and there is a high level of risk to have design conflicts. And please note that the design conflicts must be solved before the start of construction, in order to save money and times. To obtain these focus there are some significant new approaches in Architecture based on the new computational potentialities.

"Building Information Modeling (BIM) is one of the most promising developments in the architecture, engineering and construction (AEC) industries. With BIM technology, an accurate virtual model of a building is constructed digitally. When completed, the computer -generated model contains precise geometry and relevant data needed to support the construction, fabrication, and procurement activities needed to realize the building.BIM also accommodates many of the functions needed to model the lifecycle of a building, providing the basis for new construction capabilities and changes in the roles and relationships among a project team. When implemented appropriately, BIM facilitates a more integrated design and construction process that results in better quality buildings at lower cost and reduced project duration" [5].

We observe several efforts in order to the systematization of the design activity, that allow to understand how the "construction of the design", (Fig. 3) becomes more and more crucial in the current technological era, in order to overcome the increasing complexity of the world of constructions.

Fig. 3. **"Construction of the Design"**

In various computational approaches, the "construction" of design becomes somehow possible and necessary. The construction of design means thinking the design according the real constructive components of the future building. The developing of a logical construction of the design, able to include the totality of the factors [6], means to have, more and more, the opportunity to manage the challenges of this time of crisis. Computational resources offer the opportunity to make all the information, used by all actors, more flexible and interchangeable. In design process the information are construction driven and so must be easy modifiable according the needs developing during the entire process from the original idea until the end of the lifecycle of the building.

Nowadays, the concept of parameter and the dynamics of interoperability characterize more and more the construction of design according the need of construction and vice-versa.

V. Unexpected Materiality for Designers

I would therefore propose the concept of the parameter such as "the existing constructive minimum unit to be used for the construction". It is thus a constructive component, identifiable also just for one specific project. I believe that this statement can be derived from the theory and from the practice of the Architecture come down to us through the tradition the past centuries. According my research vision, "the parametric way is the link between the "bit" and the "brick".

In fact, the bit in the digital design is a brick in the real construction: is the unit conceptual minimum, to which we can reduce the complexity of the concepts of design and construction. In this meaning, the basic element is the only one that is not further divisible into other elements.

I would emphasize, how it is important to develop new methodologies focused on the relation between the traditional constructive elements that are so popular and so relevant for the vernacular Architecture as, i.e., the walls of bricks (Fig 4).

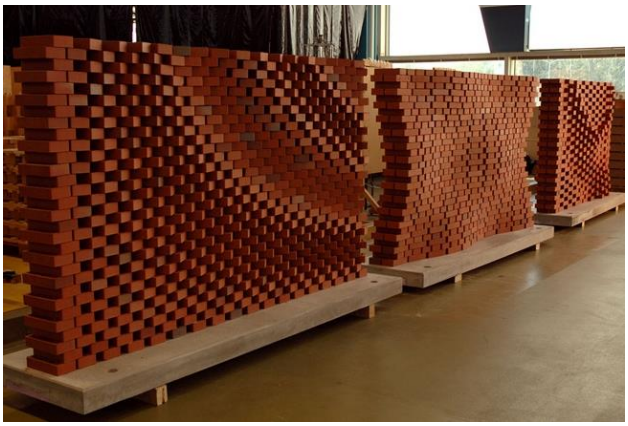

Fig. 4. **Parametric thinking as link between "bit" and "brick"**

In a new cognitive paradigm where design "is" the construction and vice-versa, we are able to use the object oriented approach focused to the constructive elements that are conceived as parametric entities.

Of course, we have to think in terms of construction, just because the object of our action is the constructed building: to parameterize every single constructive component, becomes not only possible, but also necessary. Thinking parametric offers many process improvements within traditional design practices and brings actors to work in a collaborative manner: every single decision has to be taken in a collegial manner, because every element of building must be defined by multiple parameters concerning the various skills. This methodology ensures to build architectural opera, obtaining less costs, less time and more quality for the final users. The verification of the design phase is done through the concept of simulation allowed by the use of the so-called parametric approach [7] that is becoming more and more important thanks the several benefits offered by a more cogent and convincing control of the several factors included in the design-construction process (architecture, structure, energy performances, costs…).

By now, as we know, some buildings are become real icons of the success of this new trend: one of them is the famous Water Arena of Beijing, built for the Olympics and published everywhere.

The Anaheim Regional Transportation Intermodal Centre ARTIC (Fig. 5 a,b) is one of the most recent architectural opera conceived by designers and fabricators using the logical-constructive parametric approach in order to verify of the correspondence between design and construction.

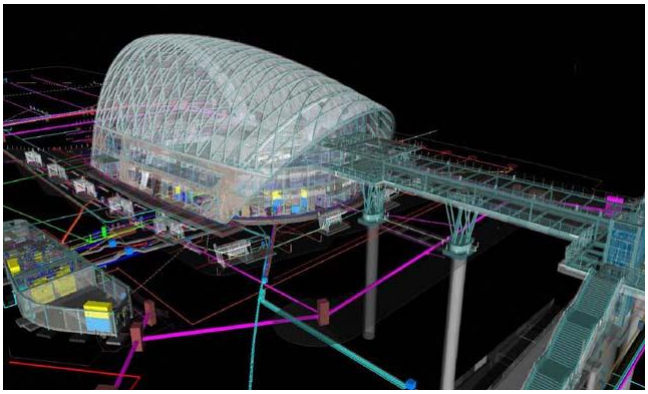

Fig. 5. **HOK Architect, ARTIC terminal, Anaheim Amtrak, USA**

The project by HOK Architect has received a citation for 2014 as "*Stellar Architecture Using BIM*" from the AIA's Technology in Architectural Practice Knowledge Community (TAP). American Institute of Architects presents these awards to highlight outstanding Architecture, designed and built using parametric technology. Several authors are writing in detailed manner about buildings that show the so important vantages of this new process i.e.: the Willie e Coy Payne Junior High School, Gilbert; the Mission Hospital - Mission Viejo, California or the One Island East, Hong Kong *"* [8].

So, it is easy to understand the success of this approach - the design through the construction - which in North America has grown up from 17% of 2007 to 71% of 2012, demonstrating impressive growth despite the recent economic situations [9].

I would underline that these results come from a new process of knowledge, based on the connection between design and construction; and this is a epistemological methodology that rediscovers the holistic nature of the design activity. In the professional field it's easy to predict that the ongoing process will be soon massively extended to all the phases of the life of a building: from the pre-design phase until to the recycle of its materials.

VI. CULTURAL AND TECHNICAL IMPACT

In Academia is very important educating new generations of future professionals that should understand deeply and critically the influence of the new methodological approaches, allowed by the current computational resource. It is important to conceive the connections between the parts of a building and to think this correspondence in terms of constructive real elements.

Probably, at the present time, the world of design has welcomed the new facilities as an unexpected opportunity to expand the designer's creativity [11], even if, sometime, we observe buildings that look like the result of a "digital game" or just the outcome of a new fashion.

From a pedagogical view, there is a high risk, because young people can be unconsciously induced to replace the real architectural fact, with its representation. But young designers should be educated to thinking, necessarily, in terms of real construction what they are imagining through the use of the new computational tools.

The world of research should set up new approaches in order to understand critically the current changes in terms of new materiality, new tectonics and new style as well. In the

current debate on the Architecture there is a deep cultural debate about the effective contribute of the "digital factor" for the theory and the practice of the architecture, specially, with respect to the ancient tradition.

From a technological point of view, to consider a constructive element as a link between design and construction, means to conceive it as a logical element and a material element at the same time: therefore its nature is related both to the theory and the practice of Architecture.

The confirmation of the theoretical vision, that is proposed in this paper, looks like an ongoing challenge; there are already important verifications: builders use BIM as (or more) than architects: 74 percent of contractors and 70 percent of architects [12]. Already seven years ago, the researches of the Stanford University Centre for Integrated Facilities Engineering (CIFE) - based on 32 major projects using BIM – have proven these BIM's return on investment: up to 40% elimination of unbudgeted change; up to 80% reduction in time taken to generate a cost estimate; costs estimation accuracy within 3%; a savings of up to 10% of the contract value through clash detections; up to 7% reduction in project time. (CIFE 2007).

Obviously, the reduction of the gap between the design and the construction, not depends by the size of the project, as, in the same year, has proven the Loblolly House (Fig. 6 a,b)

Fig. 6. **Loblolly House, S. Kieran 2007, Taylors Island, Maryland, USA**

Stephen Kieran designs (and inhabits) this house, built in the Taylors Island, Maryland: the building is born by a strong collaboration between architect and fabricator, via an innovative process to refine the design and to take advantage of the sequencing of construction and the procurement of materials for fabrication assembly [13].

The Loblolly House is the result of a research focused on the optimization of the resource. To think via parametric design and construction "as one" affects not just the control of the project but the design concept itself.

In fact, since the design activity takes place in space and time, the designer must understand implicitly these two entities before conceiving the idea of the project. The continuing development of technology can be addressed to reduce more and more the percent of vagueness implied in the transformation of the design in the construction.

VII. Conclusion

Therefore, from an epistemological point of view, the parameter is an important medium of cognition in design, because it is a medium of relation that helps designers in order to understand and to elaborate the information.

We can think at the parameter as a cognitive tool used by the designers in order to conceive and to control, the original idea, its possibility to be buildable, the resulting architectural space, the dynamic relations with the users, the link with the environment, the managing of the lifecycle of the entire opera.

As Eastman wrote *"I use the term design cognition to refer to the study of human information processing in design, using different theoretical and empirical paradigms. Design cognition has become a defined field with a high quality journal, several conference series and some major references"* [14].

The importance to conceive the opera in terms of executive details allows to overcome one of the most common risks is to give less importance to what we do rather than to how we do it.

But the new digital parametric thought is only at the beginning; and the majority of its large potential must be yet discovered and developed.

Reducing the mistakes between design and construction needs more and more powerful computational resource that allow to offer the most complete simulation as possible of the architectural opera before its construction.

As we know, researchers are developing continuously new tools in order to overcome the current limitation of the software and to offer valid criteria of verification of the information modelling methodology.

In any way, the success of the current transformations in Architecture, looks like more linked to some cognitive changes, already in place, rather than to an aesthetic revolution. Obviously, we know that the parametric approach, in its larger meaning, becomes a provider of solutions unthinkable from the human cognition without the computational process, although the designer establishes the law for developing the range of the solutions coming from the computational agent. Because there is a parametric relation between different objects but there is also possible to give different parametric solutions to the same object, the result could be somehow the risk of a "parametric utopia": no more limit for designers able to parameterize everything that they can imagine.

Therefore, one significant result of the new approaches in Architecture, is that the connection between the exploration and the creativity is powerfully amplified [15]. So, the parameter entity, because it is thinkable and buildable at the same time, can be the object of a dynamic of transformation, where everything changes or is in transforming. Can we, perhaps,

affirm that Architecture is no more "*firmitas*" but in evolution, in generation, in developing?

If this could be an no orthodox topic, however, there will other changes in the future of Architecture, related to concepts such "moving" and "interaction" that will become attributes of the buildings. In fact, one of the most interesting current research lines is the so called "Adaptive" Architecture that explores new typologies of buildings that, during their lifetime, can modify their spaces and their features according to the change of the needs of their users. This trend, will extend the current paradigm of the Kinetic Architecture that is showing a sort of design-construction in real time, in front of the users.

The "Parametric Thought" can allow overcoming of some complexities, yet related to the current need of a official theoretical systematization of the digital factor in the realization of an opera, according the usual definitions of phases and of movements in the field of Architecture.

Some authors as indicated a possible interpretation of the new powerful of computational in terms of answer to the current complexity of the design-construction activities: *"despite the fact that many, so called, digital designs are characterized by formal complexity, complexity is not necessarily a defining characteristic of digital designs. However, more than any other concept, understanding and accommodating complexity appears to be most characteristic of digital design as an approach to design. It is supporting complexity that is the mandate of design in the second digital age"* [16].

To think via parametric the constructive details, means knowing that any existing design complexity can be lead back to an original constructive element: this dynamic discloses the sense of the complexity.

"The parametric thought is an interpreter of several agents in our current complex society. Parametric thinking means thinking in terms of systems and subsystems, parts and entire, hierarchies of project and product; and leads actors to think the building like an organism that thrives on connections" [17]. About the vision to think the design of the building according its constructive logic, we have understood that is necessary not just developing a unique link between the object designed and the object constructed, but especially conceiving the two different phases of the process as only one.

The continuing development of the 3D printing technology has proved the importance to obtain objects "exactly and directly" made as they were designed. I think that the digital fabrication represents the first real "bridge" between design and construction, because transforms a digital component in real component.

What we are observing is the need of a systematization of the current new computational opportunity that, potentiality, allows us to realize better constructions.

It is necessary a *clarification of the uniqueness of digital design media can be established is to define the characteristics and unique properties of design that are emerging in new forms of digital design processes"* [18]; because we must yet identify what are the characteristics of the so called *digital media* in Architecture. The new technical and cognitive paradigms can be an efficient contribution in order to define a theoretical and practical vision in order to understand "the design of the construction" and "the construction of the design" as one. It is probably too much difficult to identify unequivocally the next step into this complicated but fascinating scenario, but I think that in a part of it will be developed this research line: how to move our vision from the "Architecture as ontology" to the "Architecture as taxonomy".

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