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Architettura... dalla progettazione generativa.
Architecture ... from Generative Design.

Dal progetto del prodotto si sta passando al progetto del sistema che serve a progettare il prodotto (processo). Le risorse progettuali, le necessità di comportamenti ottimali da par-te degli edifici, la connessione tra tecniche di stampa e prototipizzazione stanno spingendo la disciplina d'architettura a riscoprire un ap-proccio scientifico nei confronti della materia. Secondo il paradigma generativo l'Architettu-ra è considerata, al pari del mondo naturale, come una sorta di vita artificiale condizionata dai principi della morfogenesi, dei codici gene-tici, della replicazione e della selezione. Alcuni rimarchevoli edifici sono, de facto, l'icona della nuova generazione di progettisti. Nelle nuove costruzioni involucro, forma, struttura, presta-zione termica e materiali sono concepiti, verifi-cati ed assemblati allo stesso tempo, riducendo la tradizionale discontinuità tra fasi di proget-to e realizzazione: la *Progettazione Generativa*

raggiunge questo obiettivo, sfruttando lo spazio virtuale del computer analogamente ai proces-si evoluzionistici in Natura. Ci si sta muovendo nella direzione dell'"architettura per script", derivandola da algoritmi computazionali. La ri-cerca in questo ambito si apre a scenari com-plessi ed affascinanti. Si è forse giunti al tempo dell'"architettura dei programmi"? Possono le informazioni cessare di essere dati virtuali per divenire forme d'architettura?

*From designing the product we are going to the design of the system (the process) that designs the product. The evolution of the design re-sources, the needs of the buildings performan-ces, the current connection with the innovative "printing" and manufacturing techniques are pushing the architectural field to re-discover a scientific approach to the architectural fact. According to the generative paradigm, Archi-tecture is considered as a form of artificial life, prone to, like the natural world, principles of morphogenesis, genetic coding, replication and selection. Some amazing buildings are - de facto - new icons from new generations of de-signers. In the new building, shape, envelope, structure, thermal performance, materials are conceived, verified and built, all at the same time, reducing the traditional gap between the phase of design and the phase of construction: Generative Design obtains this goal, using the virtual space of the computer in a manner ana-logous to evolutionary processes in nature.
In fact, we are going towards a 'script' architec-ture... coming from a "script" of computer. The research looks like totally open to very complex and fascinating scenarios. Is it, may be, time to "programming architecture"? Can data stop being 'virtual' data, and can be considered ar-chitectural form?*
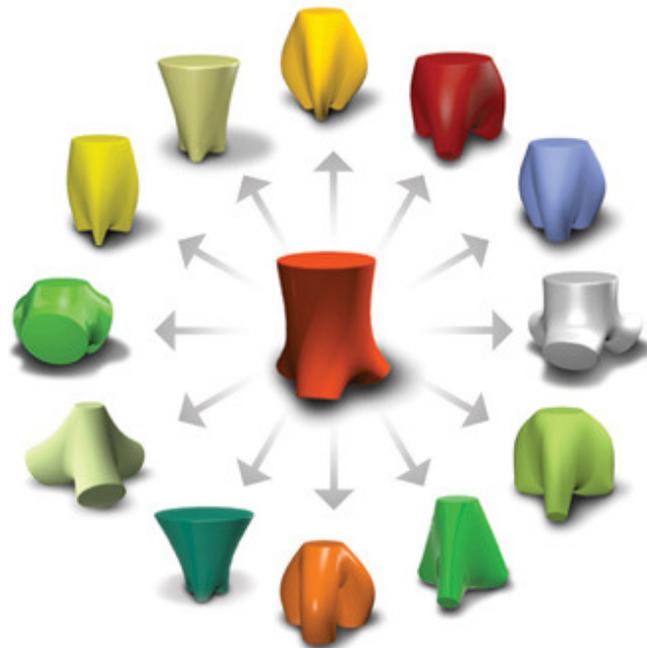
1, 2. Two icons of the generative design approach...

1. BUILDING THE POSSIBLE

It is well known that everyday something is going on in the architectural field, but in the last two decades, something easy identifiable has happened that has changed the way to understand and think the architectural design idea.

We can approach the topic starting from the concept of a new parametric architecture generated by the current computational resources. The first approach regards the object oriented design methodology, where the parameter can be the technical component as logical and constructive unit. The following approach can identify the parameter under the general umbrella of the discourse comes from the concept of Generative Art: an idea realized as genetic code of artificial events, as construction of dynamic complex systems able to generate endless variations. In the architectural design field Generative Design is also an innovative" design approach that works (like Nature), performing ideas as codes, able to generate endless variations (Figures 1 and 2). There are some methodologies developed inside the generative design concept, like the "generative components" approach: this is an associative parametric modelling system used by architects and engineers to automate design processes and accelerate design iterations. The two approaches are strong linked and, if deeply investigate, are two faces of the same phenomena: is a sort of "programmable design" changing the Face of the current phase of the Architecture?

Architects and Designers (and student as well) know famous iconic building around the world, but often they don't know that these building are developed by a generative design methodology. (Figures 3,4).

So, these are the "architectural facts". Therefore a very immediate and simple question emerges: why GD now? I think that it is possible to identify some critical factors pushing the success of the generative design like theoretic and constructive matrix of part of the current research in the architectural field.

2. COMING FROM: EVOLUTION OF COMPUTATIONAL RESOURCES

If we think about the last changes in the architectural field worldwide, the most common factor is the so called "ICT revolution": and now the first generation of architects born in the digital age is working. Therefore, we can try to understand the generative approach like a sort of natural develop of the digital mental landscape of the new generations of designers. In this way, the generative

3. BMW Munich, Coop Himmelb(l)au.

4. Glasgow Riverside Museum, Z. Hadid.

approach is a natural and logical evolution of the first parametric approach to architectural design. To sum up, we can assert that the '80 have seen the develop of the CAD dimension, the '90 the develop of the B.I.M. dimension and the current years of the Generative Design dimension.

I think that the digital dimension for the young designers has effects on how they conceive space and time: consequently this dimension produces a direct and deep consequence on their architectures, because the design activity happens inside a specific space and time. In addition, it is impossible to manage the current process: design-construction-management of the building, out of a computing dimension. So the gap between "design using the PC" and "thinking using the PC" will be more and more reduced. In conclusion, generative design is the current phase of the digital evolution of the mental scenario of designers and architects, born in the digital era.

2.1. The "new" creativity: designing the impossible?
We know how it is important, inside the design activity, the correct balance between creativity and control. The generative approach push towards new interactive techniques and tools to augment and amplify human creativity, and to use computational media technologies to explore new creative processes.
The generative approach enables architects and engineers to pursue designs and achieve results that were virtually unthinkable before. This result is very clear if we think about the new shapes produced by generative architecture.

To design these shapes, using only the human capabilities is obviously impossible. We can observe a sort of computer aided "evolutionary" architectural design that moves from the software to the real architecture (van de Zee, de Vries 2002).
It is impressive to understand: on the one hand, the creativity receives a very amazing power from the digital factor, on the other hand the digital factor can limited the creativity itself, verifying the real possibility to built what the creativity can think.
"*The Generative Art is not a technology, it is not only a computer tool but it is a way to think the possible world, a way to live our own creativeness. Each Generative Project is a concept-software that works producing unique and non-repeatable events, like music (...), as possible and manifold expressions of the generating idea strongly recognizable*

as a vision belonging to an artist / designer / musician / architect /mathematician. This approach suddenly opened the possibility to rediscover possible fields of human creativity that would be unthinkable without computer tools. […] They become tools that open new fields and enhance our understanding of creativity as an indissoluble synthesis between art and science" (Soddu 1998).

2.2. From designing product to designing process

"Generative design is not about designing a building, it's about designing the system that designs a building" (Hesselgren 2009). I think that this sentence of the director of research at Kohn Pedersen Fox Associates (and co-founder of the Smart Geometry Group), has a strong and immediate connection with the design theory of John Johansen about his vision of the so called "Nanoarchitecture".

For both research visions the goal is the product of the architectural design, is the design process and Johansen extends this process to a sort of growing built architecture.

According to several current trends in the design field, in the generative design methodology the aim is the process and not only the result. This goal is a impressive uploaded of the architectural historic tradition, i.e. about some essential factors of the Italian Renaissance design revolution, when geometry and mathematics became part of the design as systematic and methodical science.

Basically, the generative design philosophy is to translate the architectural designing into a written sequences, obtaining a sort of mix between free ideas and computational consequences. On this way, becomes possible to include and to metabolize in the architectural design non linear system or fractals too… starting from a selected parameters we can obtain a plethora of so called "generated' options.

To sum up, the attention of the designer shifts from the final product to the on going process: this is a challenge in terms of design theory, because what we are doing is to control the process to obtain a product. In different words, we can obtain a plethora of products (first step) and - into this plethora - we can select the product that we want (second step).

Designers can design the procedure for the process and waiting for the unexpected result…

2.3. Bridge between different research sectors

An important topic of Generative Design is in performing bridges between different research sectors. G.D. rediscovers the geometry and the mathematics as fundaments of the architectural design process. In addition the current computing resources allow designers to study (i.e. the envelope of a building) from several point of view, all together, obtaining a real holistic approach.

The structure of the architectural building is conceived in strong connection with the shape, the thermal performance, the phase of the construction, the future management of the building… this trend regards not only the academic field, but the professional too. In fact, we can observe how the successful of a building is strongly related to its possibility to offer an high quality level for the life of people using it: in fact a building is not just an "ornament", is not only the object of a fashion.

To obtain the end-users satisfaction, an architectural work cannot be only "beautiful", or "energy saving", or "easy to use", or 're-cyclable" … but it must "be" all these factors together. An added value of the generative software solutions is, in fact, to allows exchange data with others family of software, in order to evaluate models of light, thermal performance, structural resistance…

So, in the current professional practice, the decision about the final solution can be verified from a real holistic point of view.

2.4. Collaborative design

To b more and more powerful the GD holistic approach, needs a strong base of collaborative design methodology, in order to realize connections between the several actors involved in the design process (Shen, Lin, Barthès, Li, 2005).

To research how develop the Generative Design methodology in an Agent Based Collaborative Design System, offer to the actors of the design process a vey new opportunities to realize collaborative design strategies.

At the first step, that happens from a theoretical point of view: we know that the generative design enables designers to explore more possibilities, in less time, create better designs and efficiently create and manage complex geometric relationships. The methodology, in fact, open the way to explore different design products from the first phase of the design process itself. In the heart of the generative approach, it is written the meaning of "several", "multiple", "different", "various", "alternative" solutions.

No more just the single solution but a "family" of possible solutions where become possible to identify the more optimized result. The GD starts from a collaborative idea of the design process: the first step it isn't the final step too.

2.5 Connecting research and professional field

It is interesting to observe what happens, around the world, "inside" several famous design Ateliers… "digital" research group are born and they are working about the generative design practice and cognition.

What does it mean? Are not the digital resources "only" a (commercial) software? Simply… tools (as some "dinosaur-authors" maintain)? So, is it not enough that someone can use the digital resources? Why a research group or activity about the digital resource? The answer represents a new-trend in the current atelier design. By now, when we say that the digital resources are not only a tool such a pencil that is the same for different practicing, we have opend, from a theoretical point, a "new" way. Every one can conceive his own pencil and this pencil is different from another one. In addition this pencil may be can draw alone, or can work interactively with the actors, or can help they to conceive
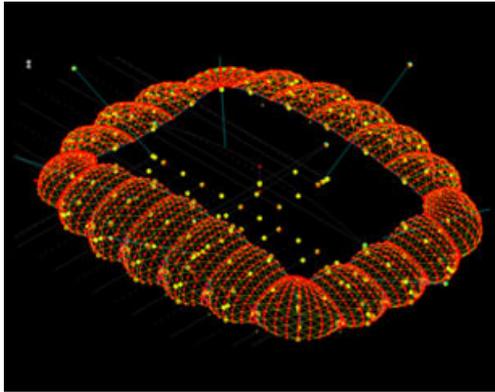
5,6. Melbourne Rectangular Stadium, Cox Architects: wireframe and construction.

7. Detailed view of the Bioframe.

8. Areal view of the Stadium.

an idea. In the current Ateliers, worldwide, designers are developing their own pencil/software, according with their character and their idea of design activity.

Therefore, every university or didactic centre should have resources spending for the generative design way, and courses and studios for this focus: how can an Architect/Engineer program the software that he needs?

At the moment, not everywhere students can include in their degree courses these opportunities to understand the connections between architectural design and software programming, but where it happens students have a added value for their future professional work.
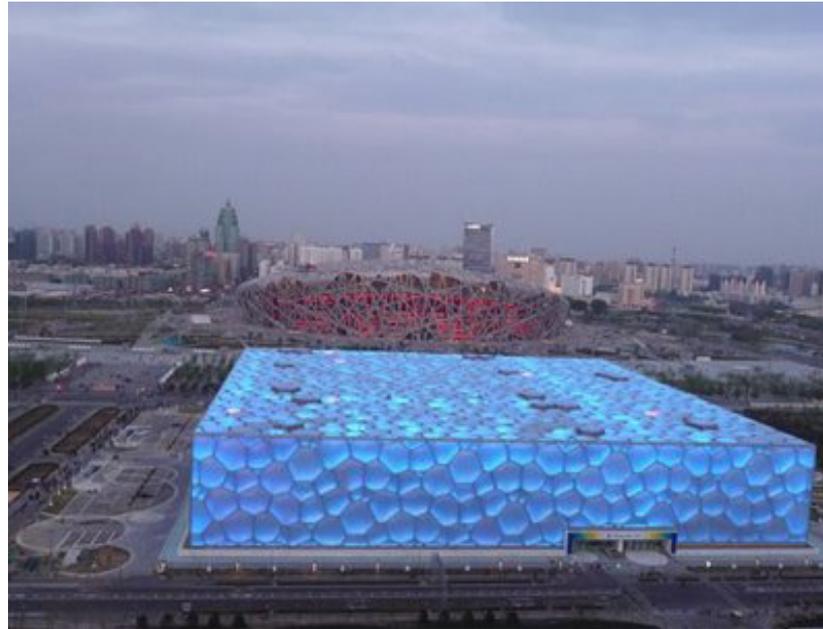
3. WORKING AT…

Thinking just to some sample of the architectural opera designed by the generative design philosophy, like the Rectangle Stadium in Melbourne (figures 5, 6).

Some constructive remarks: At the heart of the design is the Bioframe (figure 7), a lightweight steel design based on the inherent structural efficiencies of the dome. This uses 50% less steel than a typical cantilever roof structure. The innovation in the Rectangular Stadium (figure 8), which otherwise employs very traditional arch and dome principles, is the use of 3D steel elements optimised through software – with the aim being to reduce the total quantity of steel needed. In these words "optimised through software" we can understand the core of the generative approach. On the one hand, the final product walks through a selective process, on the other hand, to obtain this result, the software should be programmable according with

the designers needs. I presented this building as case of study, because two scripts were necessary to design the building. Arup used Bentley's GC parametric modeling software in order to realize a centerline wireframe of the roof for structural analysis, therefore "the first (script) contained variables to help define the base geometry and provide the ability to test alternate geometric configurations" and "..the second generated the typical lacing configuration for each shell". In addition to conduce the optimization studies of the roof steelwork, we know that Arup designers have used data exported from the model made with that software". To sum up, the final study of the process has included 24 alternate geometric configurations: ..this procedural factor has obtained a amazing economic result: "by deploying GC for optimization studies and Bentley Structural for documentation and scheduling, Arup estimates a 500 percent return on investment".

The concept of the optimization of the result and the concept of the develop of the design move together. As John Legge-Wilkinson (CAD leader for the project) said: "Realizing a geometric solution for the stadium roof structure was a critical design element of the project. GC gave us the ability to create and rationalize the roof geometry to eliminate errors that occur when manual modeling methods are used". On the one hand, the software resource allows to quickly regenerate different geometric configurations, which were used for optimization studies, on the other hand, these feature becomes powerful, because the software can export data to analysis. The result of the generative components approach? "..was an efficient and cost-effective final design". Moreover, GC allowed us In total, we regenerated and exported 24 different geometrical configurations using the GC model. (http://www.vector1media.com/news/top-stories/53-corporate-news/6199-arup-achieves-500-percent-roi-on-melbourne-stadium-project-using-bentleys-generative-components.html).

Considering another sample: the "Water Cube" in Beijing 2008 (figure 9,10).

9,10. the "Water Cube", PTW Studio and Arup: external and internal view.
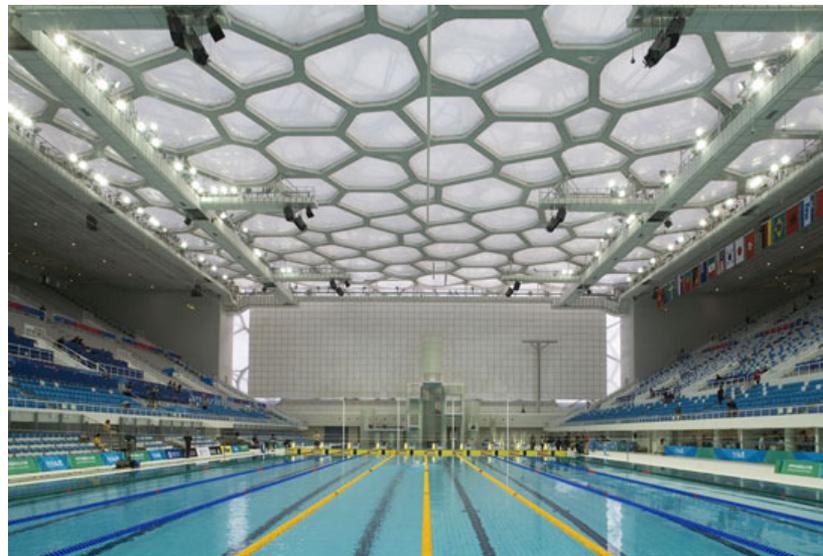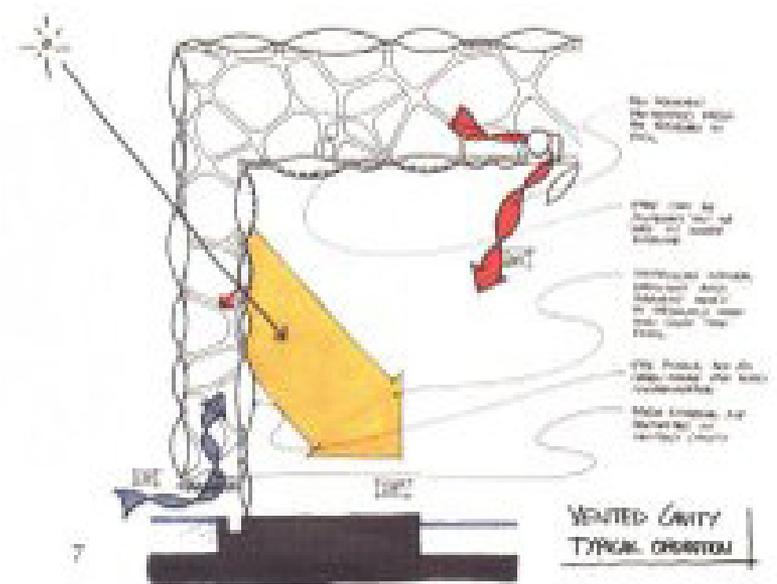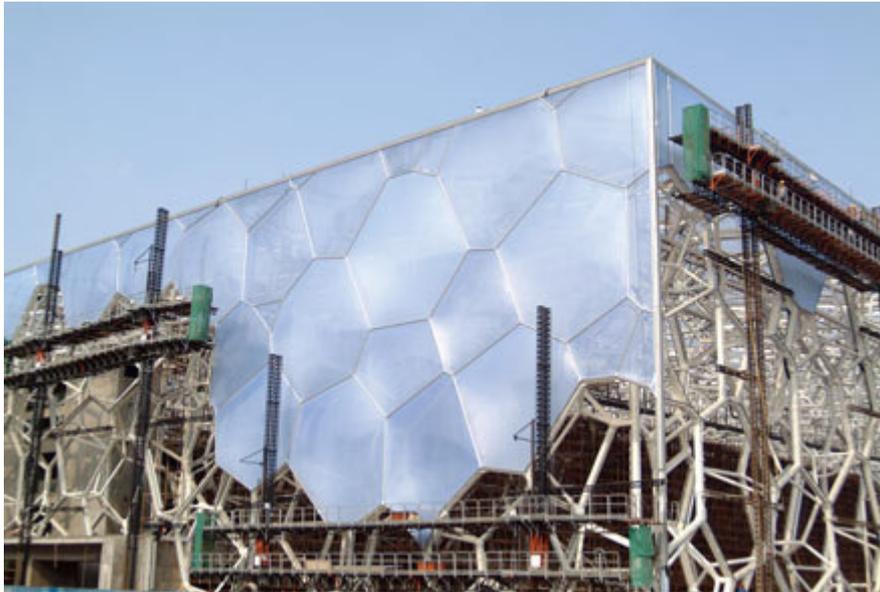
11,12. The envelope of the building: phase of construction and design section.

This architecture is the prove that the generative design is a powerful opportunity to explore techniques and ideas for design and assessment of structures, but in the same time to explore new grammar shape totally opened to the light.

Shortly: we have in the generative approach a new designing environment where Architecture and Engineering are not just mixed, but developed together.

Some constructive data: during the day the building uses the natural light (55% energy safe for lighting); the envelope is built using 3,065 blue air cushions (figures 11,12) of different sizes and made of ETFE materials, a type of Teflon (from DuPont), that can withhold the 20% of solar energy using it to heat the waters of the swimming pools. In addition the 80% of the reining water is collected by the cover and recycled and reu-

sed. But, in addition, the collaborative effort between Arup, PTW Architects, and the China State Construction & Engineering Co has produced an impressive result from an aesthetic point of view too. The shape looks like a mix of irregular water drops and change according with the colour of the sky, realizing a amazing visual effects.

The "language" of the building looks like something strongly related to the natural and biological field. Theoretically, this aspect is inside the nature of the generative art and design. The current phenomena in the architectural design is an innovative "return" to the imitation of the shape and the mechanism of the nature, allowed by the digital resources: in this direction, some vanguards of the contemporary architecture are developing a specific research and architectural style.

In the history of the Architecture we have already had some revolution x-driven. Just some samples: the perspective like "internal engine" for the Renaissance Architecture; the industry standardization for the International Style (the Modern Movement)... nowadays, are we in front of a new phase of the architectural theory software programming-driven? Thinking to the Biomorphic Architectural Forms of the Greg Lynn Studio: he was among the first designers that has produced projects that challenge traditional ideas about architectural design methods: he has integrated the computer in its design process in an increasingly innovative manner.

To sum up we can affirm that in the Lynn activity, the computer is a factor inside the process of generation of forms in response to programmatic exigencies.
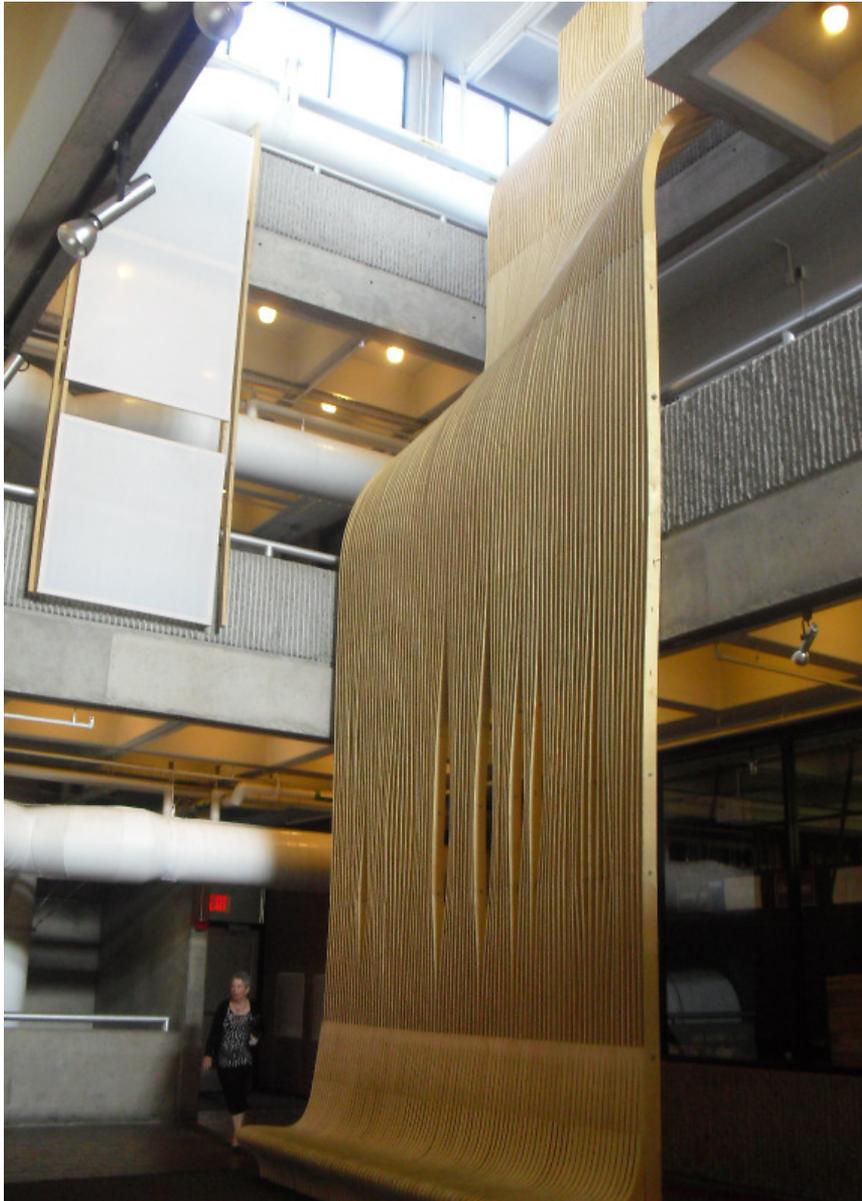
13,14,15. Generative design works at Georgia Technology Institute of Atlanta Usa.

4. NEW INDUSTRIAL RELATIONSHIP

The generative design can offer an added value to the design of the process-product, if we consider its strong connection with the construction field (industries of technical components).

On the one hand, we have a real holistic approach: in fact, designers and companies must work together in order to optimize the final result.

On the other hand, the interaction between designers and companies, must happen during the first phase of the design process. The final result, is the opportunity to obtain a real collaborative design dimension: the design phase and the construction phase become more and more related.

The design of the process-product looks like a digital continuity. What is the gap between the design of a technical component and the fabrication of the technical component itself? Just a … digital click. One of the most important strategy in order to save resources in the building construction, is to obtain a strong link between the design idea and the technical solutions, between the choice of the constructive components and their installation and performance: and that happens especially when designers are looking for innovative and no-standard solutions.

The innovative design solutions for the building construction, born from a generative design process, are the proof of the current necessity of a designers-manufacturing-workers integrated action. In the knowledge space between the design idea and its fabrication, the generative architecture offers a new added value for current designers; the generative design process can re-discover a very important concept in the history of the architectural tradition: the fusion between the industrial dimension and the handmade dimension. It is very impressive to understand, how many are the academic courses, worldwide, about the parametric and the generative design, and how many students are making digital-fabrications that are a real anticipation of the professional work [figures 13, 14, 15].

The same digital idea is the core of two different approaches: on the one hand the idea is transformed in a very large industrial production (the technical component), on the other hand, the idea is transformed just in one technical component for the specific architectural work. The final products come, both, from a 3D fabrication of the 3D design idea. In addition, according with the current development of the 3D manufacturing research, the designer can "3D fabricate" his own technological component, "directly" from his own design idea: "printed architecture" from the ornament to the house… please note, this is not a way of saying.

5. CONCLUSION

The Generative Design approach is really changing part of the current phase of the Architecture, and it is becoming the "engine" of the majority most impressive new buildings (… humans are fond of impressive buildings).

Generative Design is a real architectural design movement, that is emerging and is producing some new important questions in the architectural field, both: from a theoretical and constructive point of view. Famous designers and researchers are specifying the way. The generative approach to the design activity can be an answer to a some simple questions: "what if the designer is unclear as to what his exact goal is - that is, wants to 'sketch'? What about if the designer wishes to experiment with form?" (Ceccato 1998).

This question is very deep from a cognitive point of view and pushes to understand the core of the design activity. In fact, "..with generative art we can approach, directly, this complex paradigm of proportions and logic, and we can directly design the Beauty, or better our idea of beauty, before the realization of each single possible artificial event" (Soddu 1998).

Generative design means that the human-computer (mixed) design action is already tested: "architectural concepts are expressed as generative principles that their evolution and development can be accelerated and

tested by the use of computer models. Concepts are described in a genetic language that produces a "script" of instructions for form generation. Computer models are used to simulate the development of prototypical forms that are then evaluated on the basis of their performance in a simulated environment (Frazer 98).

By now, if "the Architecture is considered as a form of artificial life, subject, like the natural world, to principles of morphogenesis, genetic coding, replication and selection" (Holland 2010), we can say that we are in front of the change of the traditional idea of the architectural design. In fact, in a very real sense, "design has 'evolved' its own rich ecosystem, with a robust diversity of elements, dynamics, and interrelationships rivalling that of the organic system from which it derives" (Pontecorvo 1998).

Designing generative and parametric… one research filed, definitely, emerges: to investigate the connection/intersection/contamination between the architectural complexity and the computational resource. "Evolutionary Design involves using the virtual space of the computer in a manner analogous to evolutionary processes in nature. It attempts to emulate the unselfconscious design processes of vernacular architecture" (Frazer 1998).

Nowadays, in the architectural research field, we can find innovative approaches that are showing the ongoing process able to mix the human and the computational factor.

Interesting focuses about the grammar shape, are focused from the current activity of some known architects that using some "generative" resources (i.e. Alias Power Animator, SGI Indigo and Indigo Extremes, Alias, Wavefront and SoftImage).

These architectural vanguards are displaying how becomes possible to investigate architectural performance within the framework of theories based on performance parameters that are only now being theorized.

About the topic of the technical management and the techniques for the design supervision, there are significant parametric procedures - such the building information model-

ling and the collaborative design - that are not just a new powerful resources, but the possible current upgrade of the architectural design tradition too.

In fact, from always, designing means a sort of reduction of the gap between the idea of the designer and the construction of this idea (the built idea).

The design evolves in the gap between the original idea and the real construction. The Design, as a "project", happens while the original idea is verified. The way of this verification is a iterative process between the design idea and its verification; nowadays this process happens modelling the features of the future building, before its construction, using digital design methodologies.

Therefore, I think that it is real difficult to figure out for the present (and for the future) a designing activity not "computer mediated", and in addition, not generative or parametric... in fact, we are probably already going, definitely, towards a new phase of the human design activity...

The human-digital mix is, already, the current dynamics in several others knowledge fields: i.e. the computer scientists go inside the surgery room, controlling computers that "work" on the people "with" the surgeons.

Therefore, can be yet interesting to think if the dynamic of the design idea is part human and/or part digital?

We know well that our responsibility as designers and researchers is to built buildings (and architectures) that can increase the quality of the human live.

And we know that mathematical and cognitive methods (such as the Genetic Algorithm, or the Neural Networks) can efficiently help in the optimisation of the design activities. Therefore, the focus looks like different: how is this human-computer mix evolving in the architectural designing?

The Generative Design proves that we are in a sort of "second phase" of the human-computer designing activity. So, it is reasonable working on the develop of the digital resources, if the standard resources are not sufficient to follow the architect ideas. But if we need to develop the digital resources in order to obtain a no standard solutions, that means to work on the process of the architectural design. Therefore a strong link between the new architecture and the research about the new digital resources, emerges. One step more: to follow the principle of the architectural idea as something unique, the consequence is that every new building should come from a new digital resource. Therefore this new digital resource must be generated by the single architect for the single work. The goal to obtain this new scenario is very simple: programming the software according the designer idea to obtain his architectural work.

So, we are going towards a 'script' architecture... coming from a script of computer. In different words: original script, from original human idea, to original architecture. The research looks like totally open to very complex and fascinated scenario... It is, may be, time to "programming architecture"? Can data stop being 'virtual' data, and can be considered architectural form?

REFERENCES

Coates, P., 2009. *Programming. architecture*, Routledge, New York, Usa 2005.

Iwamoto, L., 2009. *Digital Fabrications: Architectural and Material Techniques (Architecture Briefs)*, Princeton Architectural Press, New York.

Frazer, J.H., 1998. *Macrogenesis: Generative Design at the Urban Scale,* in "Generative Art Conference", GA98 Papers, Editrice Librerie Dedalo.

Holland, B., 2010. *Computational Organicism: Examining Evolutionary Design Strategies in Architecture,* in "Nexus Network Journal", Springer.

Johansen, J.M., 2002. *Nano-architecture. A New Species of Architecture,* Princeton Architectural Press.

Kalvianen, M., 1998. *The ideological basis of generative expression in design,* in "Generative Art Conference", GA98 Papers, Editrice Librerie Dedalo.

Leeuwen, J.V., Timmermans, H.J., 2004. *Recent advances in design and decision support systems in architecture and urban planning*, Springer.

Littlefield, D., 2008. *Space Craft. Developments in Architectural Computing*, RIBA Publishing, London, UK.

Liu, T.Y., 1995. *Problem decomposition on restructuring shapes in terms of emergent sub-shapes*, in Tan, M. and The, R. (eds.), "CAAD Futures Proceedings '95", National University of Singapore.

Miller, P., 2010. *Public raises £ 100,000 for museum*, [online] Available from: www.herald-scotland.com/news/education/public-raises-100-000-for-museum-.1023905

Mitchell, W.J., 1990. *The Logic o f Architecture Design, Computation, and Cognition,* MIT Press, Cambridge, MA.

Piasecki, M., 2008. *Polymesh components population in Paracloud*, [online]. Available from: < http://workshopsfactory.com/category/paracloud/>

Stocking, A.W., 2009. G*enerative Design Is Changing the Face of Architecture*, [online] Available from: http://www.cadalyst.com/cad/building-design/generative-design-is-changing-face-architecture-12948

Soddu, C., 1998. *Argenia, a Natural Generative Design,* in "Generative Art Conference", GA98 Papers, Editrice Librerie Dedalo.

Soddu, C., 2010. *Generative Art,* [online] Available from: <http://www.generativeart.com>

Van der Zee, A., De Vries, B., 2002. *Computer Aided Evolutionary Architectural Design*, in "Proceedings 5th International Conference Generative Art".

Shen, W., Lin, Z., Barthès, J.P.A., Li, T., 2004. *Computer Supported Cooperative Work in Design*, in "8th International Conference, CSCWD 2004", Xiamen, China.

Various Authors, 2010. *Award Magazine V3N9*, [online] Available from: <http://issuu.com/award.magazine/docs/awardsv3_9_final_apr13_2010>

Parametric Design+Fabrication Workshop @ [A.R.C] Nicosia – the outcome, [online] Available from: http://www.parametric-design.net