Generative features: a parametric approach for exploring novel potential in architectural design process

Dr M. L. Tramontin, MEng, MSc, PhD
Department of Architecture, University of Cagliari, Cagliari, Italy
www.architettura.unica.it
Graduate Architecture and Urban Design, Pratt Institute, New York, United States
www.pratt.edu
e-mail: ludotram@yahoo.com

Dr V. Tramontin, MEng, PhD candidate
Department of Architecture, University of Cagliari, Cagliari, Italy

Premise

The use of design generative technologies, parametric in particular, opens the ground for achieving at different scales a more immediate exchange of information, exploring new alternatives in spatial and formal features.

The production of a new generation of models that are parametrically generated has been creating novel design environments in which changing design choices, formal explorations, technological assessments and energy related aspects could be intensively connected from the beginning of the process and so not “in addition” to architecture. The possibility of constructing, redefining and updating feature components could generate synergetic models of production. Buildings become evolving configurations.

This text is looking at a comparison between the design of the built infrastructure of the Li Cuponeddi Viaduct in Sardinia (2005, Italy) and the parametrically generated proposal for the bridge on the Pertusillo Lake (Honorable Mention. International Competition 2007, Basilicata, Italy). This bridge is the first conceived green bridge that is an energy producing/storing machine. In the first project the parameterization has played in the design process a fundamental but more conventional role in the transition from drawings to construction and to satisfaction of the EIA (Environmental Impact Assessment) prescriptions. Innovative parametric and generative design systems, as GenerativeComponents™ exploited in the Pertusillo project, bring a novel generative potential, especially if applied to projects with a great complexity. The production of ‘components’ and their inter-relationship, instead of a more conventional design of a single form, could become a new generative potential to shift the scale and stimulate creativity in the design process.

1. Introduction

1.1 Re-designing architectural processes with parametric systems

Innovative design methods have been stimulated both at the professional and at the academic level by experimentation on tools and concepts very significant in the contemporary architectural discourse. Recently, substantial progresses in architecture have been made thanks also to the increasing presence of computational means in all the phases of design process, to new construction techniques enhanced by digital fabrication, to the research into innovative materials and building components responding in a more responsible way to the environment. At the same time some of the most cutting-edge design systems derive directly by the building industry, as an interesting non linear reaction process: a pressing demand for new regulatory paradigms, more economical, efficient and up-to-date, to guarantee the constructability of the non standard complex forms that mark largely contemporary architectures.

An important aspect of these feeding back trends, currently developing with very different timeline of urgency and degree of acceleration worldwide, is a mutating relationship between the intuition of a certain design idea and the execution of it, with a strong impact on architectural design. The sophistication of tools capable of linking and controlling simultaneously different aspects of the design makes more efficient the transition between design and construction, suggesting more productive modalities of working that needs still to be investigated.

In our experience with parametric design systems – in particular with GenerativeComponents™ of Bentley Systems [1] - we observed a facilitation of an ongoing exchange of thoughts, ideas and actual activities. This went beyond the relevance of gaining accurate model simulation and the information-based organization of files typical of digital design technologies.

Robert Aish observes: “Many CAD applications claim to be parametric. Typically these applications use discrete elements or components that represent some application domain. For example, in an architectural domain, these elements or components might be walls or floor slabs. Each type of elements might have a series of defining properties, for example, ‘thickness’. The user gives a numeric value to define this property. Subsequently these values for the properties of one element can be changed, and that element updates (in isolation), but there are no logical connections between the components and no algebraic connections linking the value of one elements property to another element’s properties…At the next level of sophistication we find ‘solid modelling’ applications such as: Solid Edge, Solid Works, Inventor and Topsolid. These applications can correctly claim to be parametric. In these packages, complicated ‘feature trees’ can be built using geometric primitive (or features) such as rectangular slabs, cones, spheres, etc. and ‘boolean’ operations such as union, intersection difference. These applications also implement domain specific features for mechanical engineering such nuts and bolts, countersunk holes, and other typical machining operations...” [2]

In GenerativeComponents™, continues Aish: “You can draw relationships that are complete graphs…In most cases you are building a propagation network that represents your design. You are deferring the final decisions on size shape and design until later on, allowing instantly updateable change later on.” [2]

We are surrounded by many interesting applications of computational languages that drive design development in architecture and art. However, a parametric environment seems to us particularly suitable for creating a highly controlled and structured process that simultaneously enhances creativity. A parametric model built through a series of constructional steps opens the possibility for the designer to intervene to make choices in the evolution of an initial conception nurtured by multidisciplinary agendas (formal definition, structure, landscape impact, energy awareness, fabrication process). This stimulates an attitude towards exploring alternatives and updating the first assumptions.

In our practice, the use of generative and parametric design tools was definitely an interesting testbed not only to investigate modalities to spin off the potential of this new family of advanced design systems, but also to open up the research on re-designing the *course of formation* -instead of the form- in the process.

1.2 System of interrelated components

In the CAD programs we generally use, the elements don't have a memory of their generation process. The features generated in GenerativeComponents™ conserve the information on the logic of their creation. It is possible to go between the set transactions that control the geometry definition and the parameters that regulate geometrical relationships, from the basic connectivity to more complex behaviour. Thus, the feature can be regenerated with an updated logic.

Transactions describe through a set of 'constructional steps' the organization of "components" and the *design* of their inter-relationship through variables and algorithms generating *seeding files* with differential layers of immediate real-time accessibility.

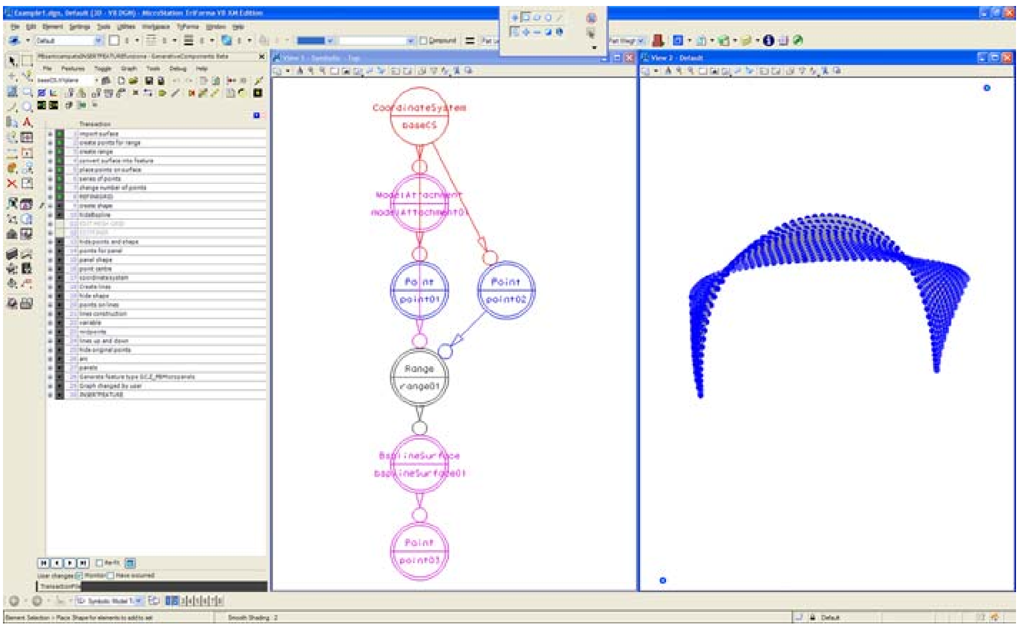

Figure 1: GC Tool Bar, Symbolic Model Window, Geometric Model Window. Screenshot from a study model in GenerativeComponents for the Pertusillo project proposal

Instead of the more conventional *design of a form*, the digital storing of information and its verification by structural, construction and environmental post-considerations, the possibility of constructing, redefining, updating, and reapplying feature components by multiple users breed actual activities of intervening into the information flow as the design advances. Various generations of models can be parametrically generated in this progress. Scale-control and measures-storage assumes changeable characteristics. The systems can be controlled with an ongoing testing of the propagation of change spreading from the updated component(s) automatically to the other interrelated components.

In addition, advanced design systems if thoughtfully channeled into the design process can heavily act for mediating the contacts and accelerating international sharing. The design, adapting to novel environments produces evolving building configurations to respond with alternatives immediately testable to site constraints, environmental issues and program demands.

The new potential to shuffle more easily the scale assumes particular relevance when dealing with complex projects involving energy production and environmental remediation - see the combined use of Ecotect™ and GenerativeComponents™ in the Pertusillo project proposal - in a advancedly coordinated fashion without losing systematicity. Particularly compelling is the possibility to generate a synergy of ideation/production of form/structure/energy and construction that sprouts from the first initial conception design, accumulating or shrinking information depending on design phasing and requirements.

These systems allow the possibility of arranging a wider number of components and calculated their interferences and mutual adaptation. The relationship between the part and the whole gets also reconfigured if adaptability to environmental factors can be thought into the same model. One of the most intriguing idea offered by a parametrical re-configuration of the endeavour in design process, seems to us the possibility to pass from a building system based on serial production to a system based on adaptable series that is potentially variable depending on the variability of the planned parameters. A systematization of the process should engender much debate to make actual a direct interaction of the geometry of complex forms with the elements of the production/factory, leading to new experimentations on spatial innovation in architecture with competitive costs of accomplishment.

We will examine in this text ways of managing the arrangement of complex set of components we experimented in the construction of the built infrastructure of Li Cuponeddi viaduct of San Teodoro in Sardinia, through a computer process that allowed pre-control of dynamic actions and construction tolerances. The final assembly resulted satisfactory for the operating traffic standards and for the EIA prescriptions. We tested a further step in our proposal for the competition of a bridge on the Lake Pertusillo in the Region Basilicata, Southern Italy. Since the first design idea, the bridge had been thought as a generative system parametrically. The first case focus on the parametric set up of the components in relation to the construction process and to the environmental requirements. The second case look at the incredible potential of re-generation and adaptation of features parametrically generated, with strong implication for constructional issues and environmental responses.

2. Parameterization of the bridge profile - Li Cuponeddi viaduct

2.1 Description of the project

The project to which these images refer is relative to the Li Cuponeddi viaduct that connects the S.S.131 DCN highway to the city of Olbia (Sardinia, Italy). This was opened to the traffic in June 2005. The main structure resulted from a combined construction technique made by paired corten steel girders and reinforced concrete. The architectural configuration of a 'double wave' both in plan and in elevation has been driven by special prescriptions for the infrastructure mitigation of Enviromental Impact Assessment (EIA).

Figure 2: View of the Li Cuponeddi viaduct

Figure 3: View from the lagoons and the belvedere

Since the first steps of the design process this operation has implied an intensive relation between the effective design production site (Cagliari), the engineering (calculation) consulting firm (Turin), the construction location of the industrial formwork (Milan) and the prefabrication factory of the ribwork of the enveloping shields (Forlì).

The Li Cuponeddi viaduct shows two separated lanes; it begins with the greatest 27 meter span between the decks, at the level of the banks, and continues with ascendent and descendant converging carriageways. The descendant 635 meter span is split into eight 70 meters long central bays, plus the two lateral ones 40 and 35 meters long respectively. The ascendant 623 meter span is split into eight central bays; the last two edges are respectively 28 and 35 meters long. The deck, in addition to the two lanes, is provided with a parking lane, 3.50 meters wide, separated and protected by a raised kerb 50x20 properly marked, with a 3 meters wide sidewalk, in the middle, to allow the stop of the birdwatchers. Therefore the deck shows, in the horizontal plan, a variable section due to the dimensions of the sidewalk. The lateral shield that has mainly the function of a balustrade, is constructed in precast concrete adapting to a curvilinear path, both in longitudinal and in transversal section. The shape of the shield allows veiling the main steel structure confering to the architecture an appearance that remembers a wavy motion.

The system pier-capital is similar from an aesthetic point of view to the deck course. The pier shows an elliptical section that is variable and increasing from the capital, where it presents the shortest transversal section, to the insertion into the plinth. The capital is constructed with two brackets embedded at a straight angle in correspondence of the transversal axis of the pier, forming, in the superior plan where the deck loads are expected, a cross of about 9,20x2,90 meters. The insertion of the two brackets into the pier is obtained with curvilinear connections to confer to the architecture the appearance of a goblet. The viaducts, with a continuous girder frame, are bounded to the lowest banks.

2.2 Parametric construction of the precast concrete reinforced shields

The viaduct shows a mixed construction system steel-concrete with a structural diagram of a 10 span continuous beam. The steel girder frame is constituted by two adjacent beams, with a 7.20 meter span, realized with a framework scheme of costant height and crossing diagonals. The beams are then connected by means of horizontal bracings above and below and vertical diaphragms, in a way that they can constitute a box beam stiff to torsional stresses following the Bredt model. The slab collaborates structurally with the metallic structure below by means of electrowelded connectors type Nelson on the above longitudinal edges of the frameworks.

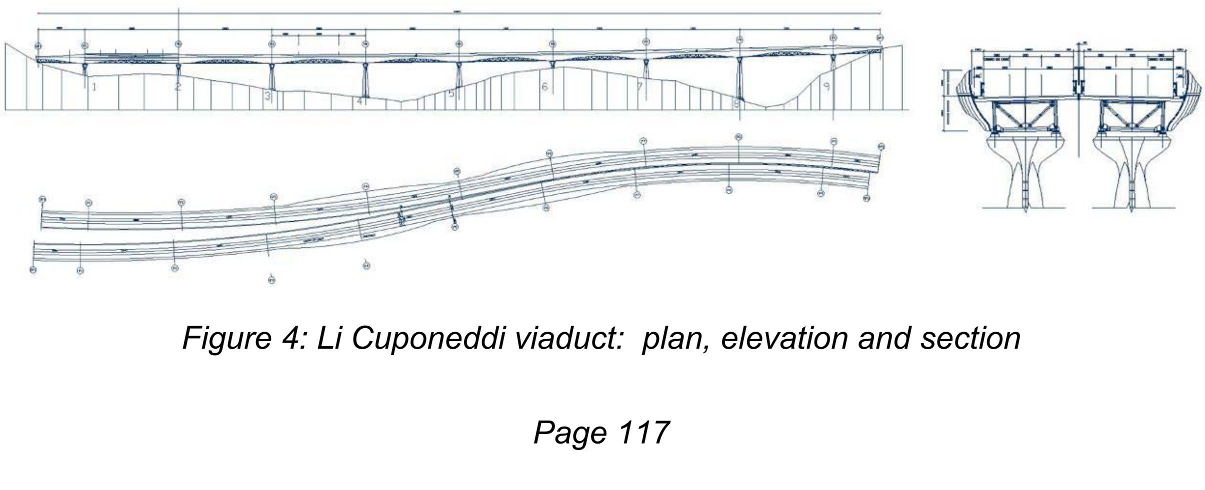

Figure 4: Li Cuponeddi viaduct: plan, elevation and section

The parameterization in this project played a key role in the normalization of the drawings of the girders and of the industrialized formworks relative to piers and capitals through the exchange with the various actors involved and the optimization by consecutive phases due to the specific technologies involved in the process.

Another significant application of the work in this project was related to the construction of the enveloping shields. The design was done in the office in Cagliari and transmitted to the prefabrication works, with particular care to the gain joints into the spatial bend, which drives to an architectural configuration in a “double wave” shape.

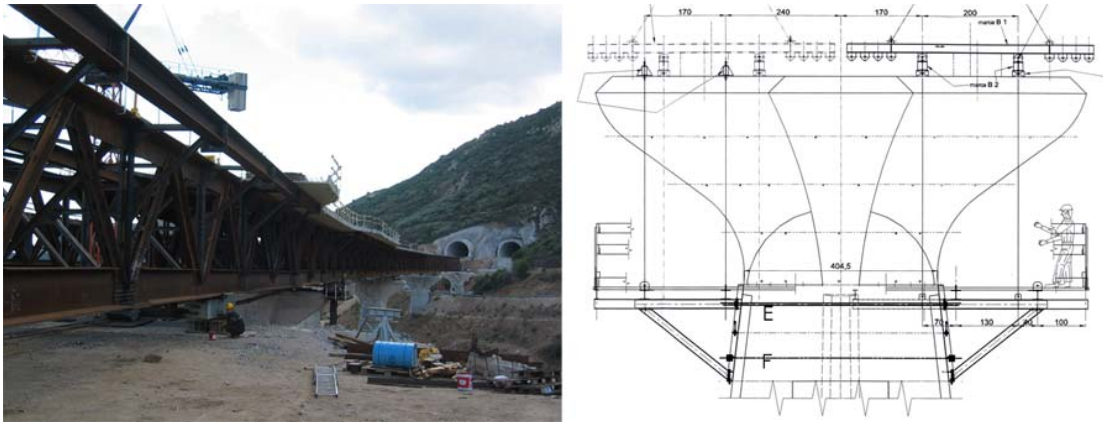

Figure 5: Corten steel girders and capital formworks

Particular attention for the design, construction technique and assembly logic was made at the factory in Forli for the prefabricated shields with a height range from 2,90 meters to 7,50 meters. Their joint chair welded to the edge of the deck marks the center of gravity of the individual shield to accomplish the difficult traverse assembly due to the strong winds blowing through the Cuponeddi deep valley.

Figure 6: Construction and assembly of the sinusoidal concrete shields on site

Figure 7: View of one concrete shield component and the overall sinusoidal enveloping shape

3. A generative approach driven by parametric methodology - The bridge on the Pertusillo Lake[3]

3.1 Design concept

In the project for a 700 meters span bridge for cars and pedestrians situated in a natural protected area on the Pertusillo Lake, (Potenza, Italy), parametric design plays a critical role in allowing a synthesis of the formal, structural and energy-related premises of the proposal. This affects both the effective design model production and the team operational work as the project advances.

The model developed in GenerativeComponents™ facilitated in fact extremely an ongoing investigation of alternative solutions during the competition phase. After defining the main model relationships, the team working in different locations (Cagliari-Italy, London-UK, Munich-Germany) has been allowed to continuously adjust design scenarios as an interplay of form/structure and energy considerations. This process results in a still open balance between design imagination and efficiency of the production.

The technical and structural features of the bridge actually define an experimental formal solution that integrates the insertion in the environmentally sensitive context with energy strategies innovative for a road infrastructure.

[3] Honorable mention at the International Competition for design project of the bridge on the Pertusillo Lake in Val D'Agri, May 2007. Project team: ASPX/ Ludovica Tramontin, Vittorio Tramontin, Giuliana Secchi, Alessandro Uras + Kristine Mun. Structural engineering: Asko Fromm. Fabrication algorithm for the physical model: Davide Madeddu.

The impact on the landscape of the Pertusillo Lake, characterized by particular aesthetic and environmental valence, is controlled sensitively with a low profile course, slightly curvilinear to simulate a phyto-morfology of a stalk of a lacustral plant. The phyto-genesis creates a metamorphical appearance thanks to ligh-tech and photosensitive metallic and transparent materials used for the skin. This brings a continuous artificial built / natural landscape variance depending on the incident rays of light and the reflections modulated by the waves of the water, varying in the day and night, with the change of the local climate, and with the seasons that follow one another.

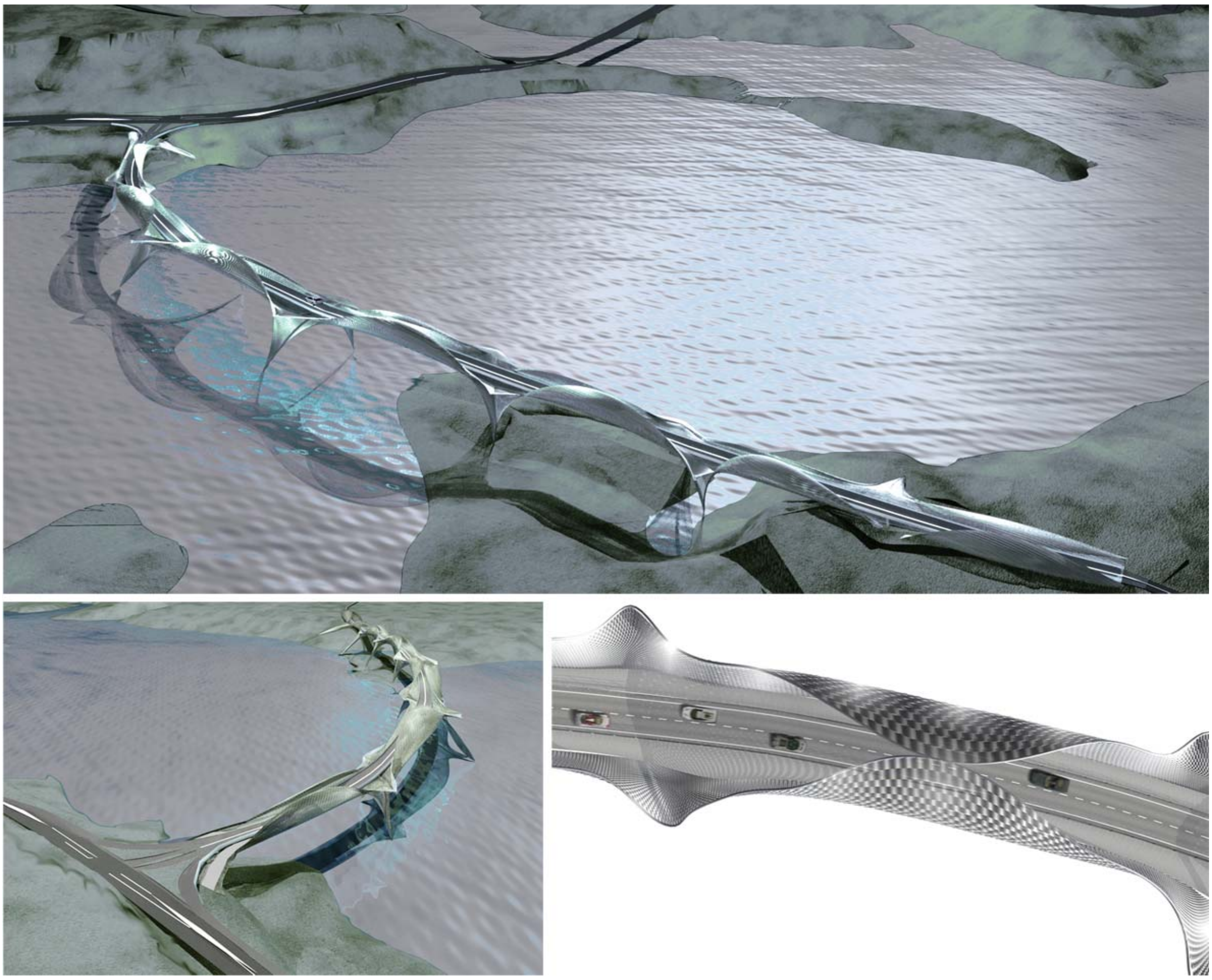

Figure 8: Views of the proposal for the bridge on the Pertusillo Lake

The architecture of the bridge so defined wants to become an interaction environment hosting the possibility of a hybridizing process that changes the built in landscape and the architecture into a temporary geography. The search is therefore orientated to a naturalistic condition of the infrastructure characterized both from physical and virtual duality.

Thus the project discuss how to establish in the insertion of the bridge a novel alliance with the landscape that, starting from fixed category of reference, becomes almost by paradox necessity of a continuous mutation for the project and more generally for the established conditions of architecture: multiple design scales, sustainable transformation processes, building technologies.

The formal configuration derives by tubular steel arches that constitute the ribbed support of the continuous steel mesh generating a homogenous shell structure resisting to eventual seismic stresses. The arches show different spans and different profile heights standing organically out in the the lacustral landscape. The tubular steel is founded in subalvee concrete caissons on pilework.

Figure 9: Views from inside the bridge shell structure

3.2 A photo-sensible skin for the bridge

The 'visible' skin of the architecture is constituted by light wavy and modular screens in aluminum and polycarbonate that alternate to favor the enjoyment of the landscape as one drives/walks across the bridge, reducing the impact of the vehicles in motion at the same time.

The skin was calculated in GenerativeComponents™ by a parametrization of the digital model of the surfaces in modular components, allowing an interactive relational work between structural, energy hypothesis and variables controlling the geometry of the form generation. The parametric analysis was deployed towards a discrete understanding of more elaborated geometries into relational connections between individual modules, through the analytic control of parameters programmed on the solar exposure of the different parts of the surface and on the structural behavior of the shells.

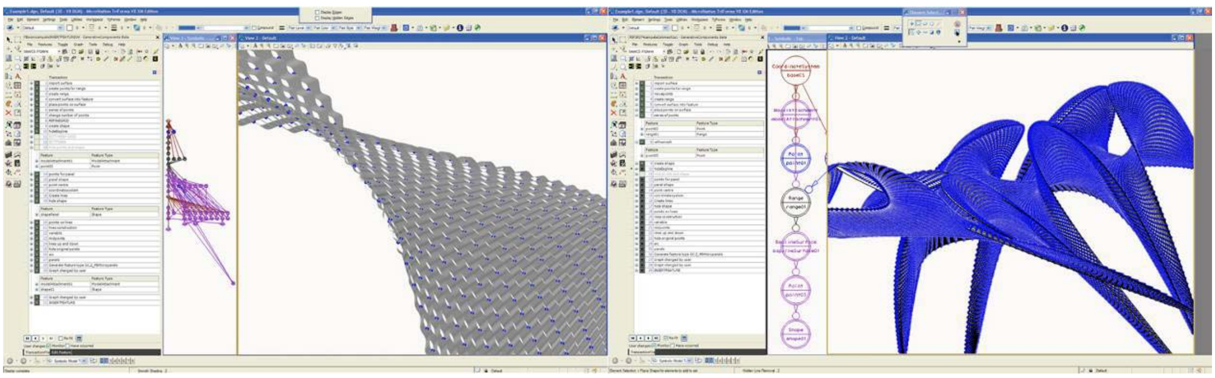

Figure 10: Generative diagrams of the envelope and the structural shells

With a parametric elaboration of this model using the powerful replication algorithm in GC, element multiplication, scale variation and details implementation affects the overall organization by gradients or continuous variations.

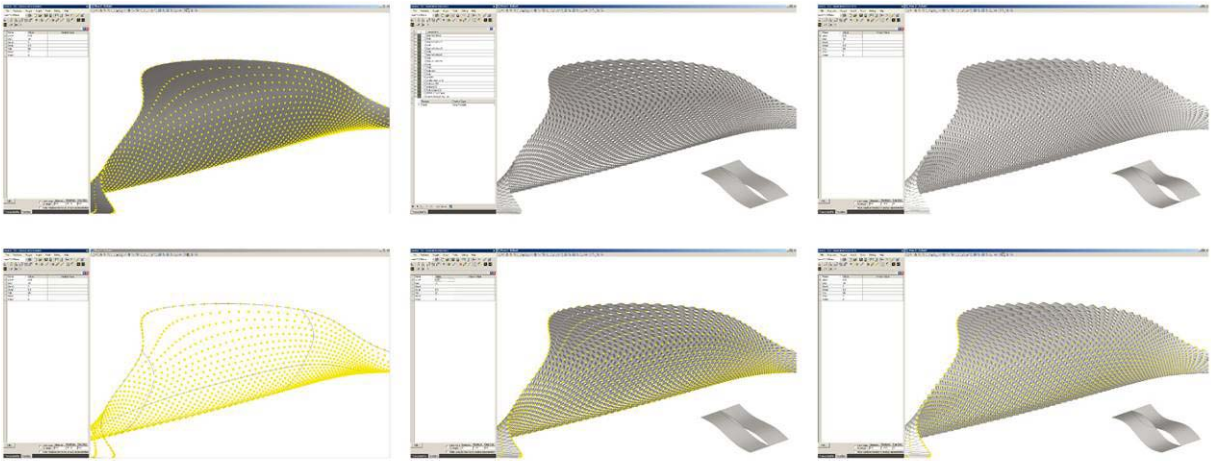

Figure 11: GenerativeComponents™ diagrams: parameterization of the skin

A parallel analysis with the software Ecotect™ of building environment design allowed defining the shape in base to the best exposure to the solar radiation. The most irradiated surfaces are provided of semi-integrates photovoltaic modules for the electric production of energy. The choice of the wavy envelope in aluminum derives also from energy considerations. It allows three different orientations of the photovoltaic modules inside a singular component of the envelope according to the better exposure in the three-dimensional development of the surface. It results in the possibility of exploiting the greatest surface of the envelope useful for the integration with photovoltaic modules.

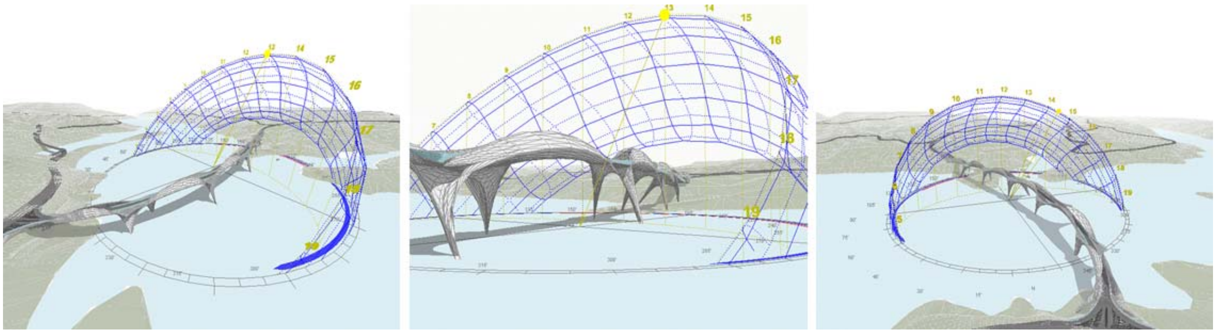

Figure 12: Model of the bridge in Ecotect :the parallel analysis GenerativeComponents/Ecotect allowed a form generation process based on energy aspects

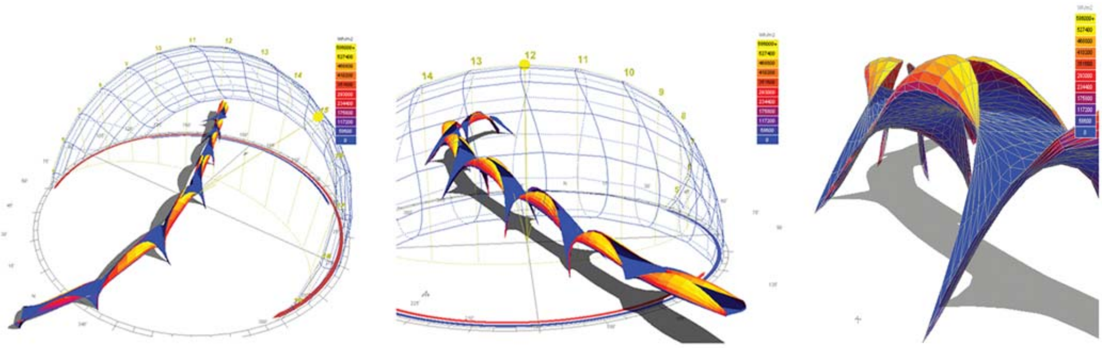

Figure 13: Diagrams of the solar radiation incident on the bridge envelope, which defines the best zones to apply photovoltaic modules

The orientation of the microlouvers - the double wave components of the modular aluminum skin - is totally reflective in the surfaces at high energy incidence and produces an effect of 'evanescence' and darkening of the photovoltaics. The concavity of the microlouvers favors the reflection of the sun rays conveyed partially in the photovoltaic cells for the production of energy, increasing so the global efficiency of the system.

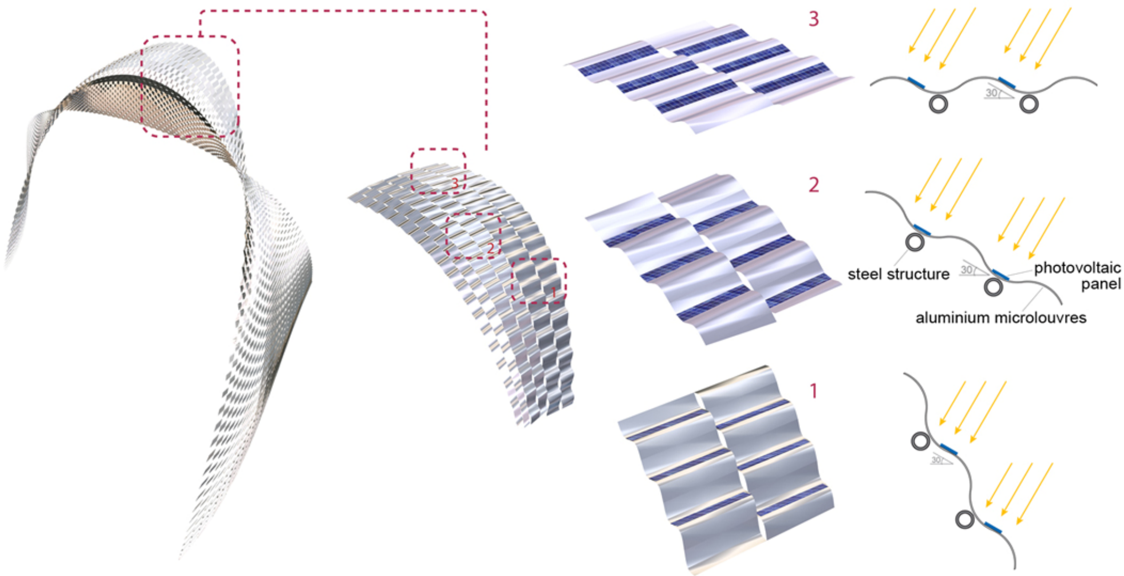

Figure 14: Different positioning of the photovoltaic modules in the curve aluminum microlouvres depending on solar exposure

The structural mesh of the bridge and the photo-sensible skin is therefore derived by a parametrically driven mediation between static considerations, formal analysis aimed to reduce the impact on the landscape and energy evaluations. This trial is reflected both on the global scale of the three-dimensional unwinding of the shells and to the microscale of the individual component of the skin.

This bridge is conceived as green bridge that is an energy self-producing/storing machine, with many important social and economic benefits. A preliminary estimation shows that though the energy harnessed by the bridge can be directly used for lighting the bridge at night, the majority of the power produced can be sold to the network and nearby customers. The big investment necessary for the photovoltaic plant may be paid back reasonably quickly considering the incentives and subsidies for the renewable exploitation. The sustainable energy concept in turn contributes to alleviate the negative impact of the bridge of the cars' emission by globally reducing pollution.

4. Conclusion: widening the horizons of the research

In this paper we report our experience in deploying parametric design –different systems applied to two projects spaced out over 2 years- as our contribution in addressing the question of how advanced parametric design systems can be channeled within the different stages of the architectural design process as a generative potential.

In the built infrastructure of the Li Cuponeddi Viaduct project the parameterization has played a fundamental role in the drawings normalization, especially in the transition to the construction phase and the satisfaction of the EIA prescriptions. The most recent parametrically generated proposal for the bridge project on the Pertusillo Lake offered the opportunity to the team to work, more than with a univocal solution, with alternatives of mediation between exploratory formal solutions sensitive to the delicate context, logic of structure and materials, energy and environmental performance, and to convey these investigations into architectural constructs from the first design conception. A relational setup of the initial model brings the possibility of adjusting changes easily, if compared with transmission of a more conventional digital model.

In Li Cuponeddi viaduct of San Teodoro in Sardinia, the parameterization involved only particular factors of the projects related to the geometry of shields, to the impact on the landscape and to the specific methods of construction. We feel we gained a more advanced experience in our proposal for the competition of a bridge on the Lake Pertusillo. Since the first design idea the bridge had been thought and developed as a generative system parametrically. Allowing the flowing of information, through parametric design, in a continuous fashion across the design process, from the initial planning to the accomplishment of a prototype, increases the chance of the connection between data and geometry and reverberation of a local change on the global system. A large number of features parametrically controlled - not drawings but families of mutational generative elements - can be created, updated, re-informed and eventually integrated into more conventional design environment, at different stages and scales.

In our opinion the application of the latest parametric design systems to projects with a great complexity create an actual chance to work not on the *final form* but to intervene *in the formation of the design process* with multi-disciplinary influences. Changing the environment in which contemporary architectural practices can recognize their contemporary physiognomy and stimulating imagination towards a generative endeavour in virtual and actual adjacencies, seem to be the most challenging aspects to explore.

References

[1] Aish R.; GC Workshop – Erica Calogero_ notes from March 17th; 2005.

[2] Aish R.; Bentley's GenerativeComponents. A design tool for exploratory architecture; Bentley Systems; 2005.