Cooperative Design to Construction
A sharable model for non-standard timber construction

Abstract

Architectural design is confronted to a renewal of formal vocabulary regarding the advancements on computational techniques. Non-standard architecture demands a hybrid approach regarding design and construction. It revives common borders between architectural and technical design. However, the respective digital assistance is confronted to discontinuity. This paper reports on part of a research activity aiming at elaborating a sharable model, which by integrating construction knowledge assists the emergence of constructible geometry for timber construction.

Introduction

Stemming from the world of industry as a strategic device to exceed the Fordien model the notion of collaborative approach is exported in the 90s in the field of building. Furthermore, since this approach is based on essentially organizational (quality of the processes) and economic (improvement of the productivity, time saving) arguments, it gently touches the creative dimension of architectural design. Most of the architects, although concerned as economic agents will feel only little involved as designers and creators of space. It is true that neither repositories, nor IFC affect the architectural scene of the end of the XXth century.

In 2000s a consequential break is introduced into this fact. In the beginning of the XXIth century two currents of thought emerge which will touch in various ways, the architectural practices as collective activities and creative activities as well.

The sustainable development induces an environmental awareness which reforms both the ethics of the constructed work and the model on which the dominant modern architecture is established. The appropriation of the concepts of vernacular relays, in its way, the question of the creative activity as task of interpretation of knowledge, solutions and even buildings bequeathed by the history of the men. In the break lauded by modern movement, a form of cooperative continuity was set where every proposition enriches previous experiences to form what Christopher Alexander called "patterns" [1]. And if Alexander qualifies these "patterns"

and their language, as solutions of "nameless quality" we could in the same way speak of "anonymous cooperation" or of "extrinsic cooperation" to characterize the cooperative process which underlies these approaches.

Moreover, the ecological point of view leads to new concerns such as the economy of the resource, building health or the end of life of the building. While some people see a new field of constraints in this approach, some take pretext for a return to an idealized nature and others find it capable of exceeding the limits of "the sublime architecture" or "the primitive hut". We shall quote some examples pointing the emergence of new dynamics.

The decomposability of Peter Zumthor's Swiss pavilion in Hanover (Germany) expresses radically the idea of the end of life in the project. The project of Wang Shu in Hangzhou (China) made from the recycled materials of the old districts asserts itself as a critical sedimentation of the Chinese urbanism. Even the more "high-tech" approaches of Stephan Behnish like the Wageningen Institute (Netherlands) are a kind of capitalization of the scientific and technical knowledge in service of architectural poetics.

The non-standard architecture introduces another break. It brings for its part a new vocabulary where the non-Euclidian geometries confront different modes of manufacturing and construction, which are strongly instrumented by digital technology. Individualization of forms as well as their components - thanks to parametric modelers and numerically controlled machines - destabilizes the approaches based on monotonic composition of standardized elements. The right angle is not any more an absolute which cannot be got over no more the serial repetition of a constant component is the only economic shape of architectural poetry. Essentially formal at first, non-standard architecture seeks to find a technical and economic but also environmental rationality to cut itself from the easy domain of the digital images and go into that of more concrete materials and territories.

Here still we can observe a questioning of common borders of architecture and manufacturing. The architectural design establishes itself by taking supports on possible variations in production phases whereas the shape, dimensioning and the composition of components arise from the design process. This time we shall speak of "intrinsic cooperation" to indicate the strong level of integration between the various dimensions of the conceived object.

These two currents, although distant and without direct link, are not that much foreign one to another. Strongly synchronous, they reflect the same critical questioning as well as a type of refusal proposed by the various postmodernisms in answer to the crisis of the modern productivism. Far from aiming at the universality assigned by CIAM to the modern architecture, they try to find the local sense and the difference.

They infer moreover a revival of the knowledge of the actors as well as changes in the borders of skills established in particular between architecture and engineering. By advancing the necessity of holistic approaches, they reinforce the idea of crossing of skills, expressed, but with not enough effect, by the collaborative engineering.

While for a long time the collaborative approach has led to the development of tools of exchange, in the new context, the collaborative concepts start to deal with architectural practice in it's creative dimensions. By reviving the notion of cooperative design-construction, it is the very contents of what is exchanged which is being transformed.

Non-standard design-construction

Within the framework of this context, our research work aims at understanding and making possible the idea of a continuous process from early stages of design to the manufacturing of non-standard forms. Several symbolic realizations of this approach reveal not only a revival of the architectural vocabulary but also a paradigmatically deeper change in the process of design.

The CET of Budapest by ONL, "Strata tower" of Asymptote in Abu Dhabi or still the "house hydrogenates" of Greg Lynn are examples showing how architectural design and technical design, too often separated, establish new intense links. The processes of manufacturing guide widely the architectural volumes whereas these last ones imply strict requirements regarding components. The component is shaped just as much by the architectural form as it shapes it.

Form, structure, envelope, detail, manufacturing and construction form an inseparable network. Any change of one of the constituents of the network modifies the others. If the current architecture attempted to isolate each of these concepts, the non-standard architecture makes every effort to reconnect them.

In fact the non-standard architecture invites to rethink as much the geometry as the technical aspects. It breaks the strict borders of the skills to incite them to cooperate by integrating them into a common model.

This vast domain, which involves researches in geometry as well as those in computer science and engineering, is the subject of numerous works today. We could quote works so different as those concerning the geodesic structures [10] those relative to parametric design of the assemblies [4] or still those more geometric [11].

Similar works in the field

Architects often claim they cannot think of a solution, or proceed with the design, when they don't know how and on what it is going to be realized. The decision about how the design's result will be fabricated is thought of

usually as the last question. The idea of digitally bridging design and materialization processes in architecture has been explored by several researchers.

Fabian scheurer [12] and his team have questioned through several projects (Camera Obscura Trondheim, Hungerburg Funicular Stations Innsbruck, Centre Pompidou Metz) the materialization of a digital model. Based on logic of component as he explains, and the information needed to describe a component, their experiences challenge the translation of a non-scaled digital model to a one to one real object. Shifting the definition of "complexity" from formal configuration to the context of information processing, the firm works on the basis of parametric description of components to be fabricated. The use of parametric modeling is because of its adaptive capacity to changing context of construction and manufacturing constraints.

Their experiences reveal that construction, assembling process and fabrication methods, bring post design processing to the geometric description of the final shape. In translating design data to manufacturing information one crucial issue concerns construction decisions. According to Scheurer [6] in the information flow between design and fabrication an important part of the bridge between CAD and CAM model is the construction dimensioning. Detailing and precise two-dimensional documents needed to control the CNC machine are not provided by the free form modeled in a CAD environment.

Researches done by Sass, Michaud and Griffith [4] address another issue concerning post-design processing; the problem of assembly modeling. They characterize the process of design to fabrication as following; the process consists of four steps; preparation of a first three dimensional CAD model, elaboration of a construction model (as they name it) containing description of components adapted to local geometry, providing two dimensional arrangements of 3D components to be numerically fabricated and finally the assembling of fabricated pieces.

Focusing on problems posed by assembling of fabricated components, they question the relation between shape modeling, structural and assembling systems. They explore methods of integrating assembly modeling in the CAD model so that design's result be less altered once arriving at assembling phase. Also based on logic of component or sub-object the issue of their researches is based on physical and mechanical behavior of components at their connections.

They have previously developed a plug-in tool – based on a bilateral network of connected ribs – to rationalize complex geometry (figure 1). As explained above the study is focused on structural efficiencies of bilateral assembly of free form surfaces. This is why parameters related to physical and mechanical characteristics of joining (connections) such as density, friction and thickness affect the behavior of the geometry and are therefore

used to generate the bilateral network. Both vertical and horizontal ribs are created based on number of divisions defined by user. Ribs are joined with wooden wedges and a developed algorithm calculates the geometry of the intersection.

Fig. 1 the result of the application of the plug-in on a free form surface; the surface is transformed to a bilateral network of connected ribs. (Sass, Michaud, Griffith)

These studies reveal the importance of integrating construction and assembling knowledge as semantic information in the geometric model. They indicate also the use of parametric modeling in this regard. However, they reveal on the other hand the lack of a generic parametric model - especially in the case of timber construction - to better assist the process of design to construction. A model, which - by integrating post design information - is capable of supporting cooperative design-construction process and enhancing the degree of constructability of the final design.

Sharable model

It is evident that for any form of cooperative activity, the idea of a continuum should be based on a common or sharable model of data. However, analyzing these works it seems that most of them are focused on special phases of design-construction process. Such an approach goes in contrast with the idea of continuum and would strongly limit their field of application.

We thus propose in our work, a sharable model; a model that provides both architects and engineers with the possibility of sharing divers points of view and ideas via a common model. Based on a generic approach, the

model provides also, a parametric representation of different families of wooden structures and respective assembling methods.

Morpho – constructional families

David Georges Emmerich [3] characterizes the process of morphogenesis as following:

"Any act of creation is a sharply hierarchical process which naturally goes from abstract to concrete, and which we can even chronologically decompose into five main phases - while being aware that we can go back cyclically several times on these phases - which are thus:

- Morphological (to imagine)
- Metrics (to give dimension)
- Mechanics (to stabilize)
- Physical (to calculate)
- Technological (to execute)"

Although this definition is general it is still relevant to our object of study. If we indeed do not want to be limited to the vocabulary of the forms of buildings, the non-standard architecture distinguishes itself at first from standard productions by the narrow interrelation between the general shape of the envelope and that's of the structure and the physical components that constitute them. The variation of one is able to engender the variation of the others including in their morphological, mechanical and metric dimensions. Also we specify that the technological dimension is for us restricted to the data of manufacturing, assembly and implementation.

To propose a model enough generic passing from a geometrical shape to a construction model, which can be used as well for static analysis as a given source in a digital manufacturing process, we established our typology by analyzing more than 50 recent realizations.

Six main categories of "shaping" are identified each of which can be sub-categorized: the pilling-up, the stratification, the tessellation, the meshing, the armature and the membrane.

The piling-up refers to the superposition of horizontal regular or non-regular elements. Following a corbelling system it can support upper superposed elements. The friction between the elements cancels the horizontal forces. A distinction could be made between layered piling-up and modulated piling-up (figure 2). The stratification is different from pilling-up because of the flat nature of elements. The position of layers creates two classes: horizontal and vertical stratification. The tessellation (figure 3) splits up of a structural surface with similar (or no similar) elements, which is usually compatible to the structural frame. Differences

between facets would be in terms of shape (triangle, rectangle, pentagons) and the folding angle between them. A distinction could be made between facets and waffles.

Fig. 2 Example of modulated pilling-up: BWIF Sculptures, Bergen, Norway **Fig. 3** Example of tessellation: Saint Loup chapel, Switzerland

A mesh (figure 4) here is considered as a grid of arcs or network of bars. Interconnected bars are subject to traction and compression. Meshes can form sorts of structural free forms enveloped by a subdivided surface. The (structural) frame or armature (figure 5) is a composition of various structural elements that build a three-dimensional shape. This shape could receive an envelope surface. And finally the membrane is a continuous structural surface made with linear (planks) or surface (panels) elements but assembled with no angle. Vaults or shells represent variations of the membrane.

Fig. 4 Example of a mesh: Weald **&** Dowland museum, Chichester England **Fig. 5** Example of Armature: Observation platform, Trondheim, Norway

This typology allows us to describe the main non-standard structures for timber construction and to develop structural concepts of the generic model.

Generic-Parametric model

The generic parametric model was developed based on families explained above. The model provides a parametric description of topological and morphological behavior of predefined techniques of construction and assembling – knowing that the assembling part is not still integrated. To digitally assist the bridge between design and construction, the model represents an intermediate phase. It allows for a transformation from a general volume to a detailed representation of components.

The model (figure 6) handles, firstly, the transformation of a free form surface to a structural mesh, and secondly, the materialization of the mesh, which results in a constructible volume.
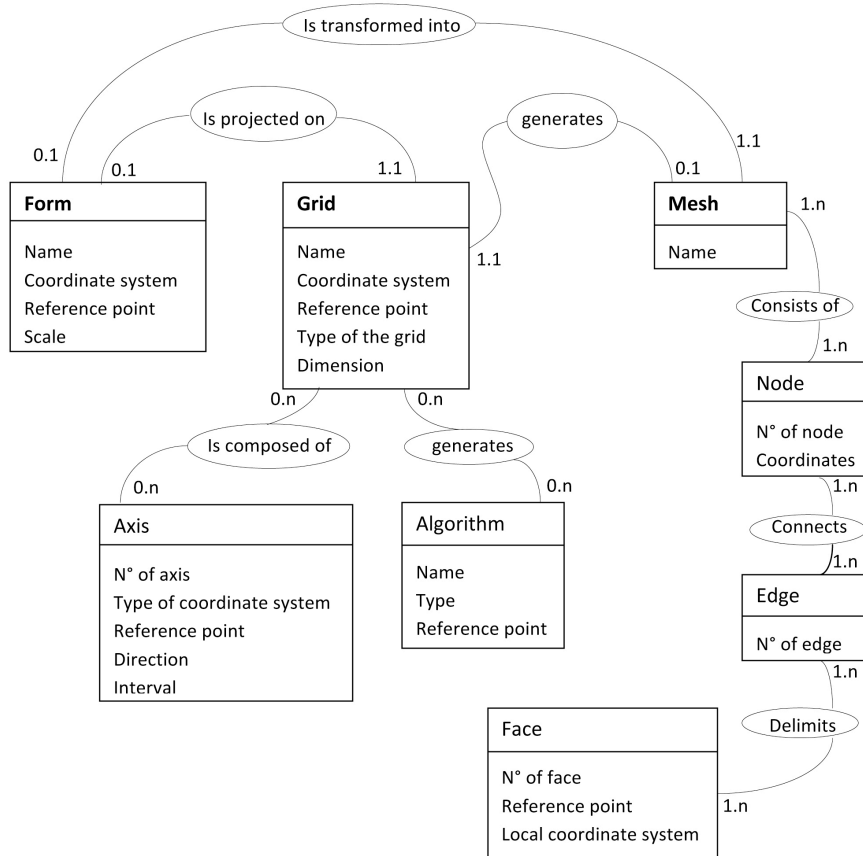
Fig. 6 Relational model, assisting the intermediate phase between design and construction

Main concepts of the model are; 1) a grid – an ensemble of axis and points – 2) a section or better to say a profile and finally 3) nodes or intersections between axes of the grid. The grid is here a sort of operator,

which integrates part of construction knowledge. The model will then give a parametric definition of the grid and sections (profiles) specified for timber construction methods. Parameterization of nodes will handle assembling.

Two kinds of 2D grid are considered here: regular and irregular one, where the irregular refers to a grid created by random mathematical operations and the regular one can be either oblique (containing orthogonal) or polar grid. As the first step of the development we focused on a two dimensional regular grid.

An important parameter concerning a grid is the number of superposed sets of axes or better to say number of axes passing from each node. It varies from 1 to 3, where the first case concerns layering and stratification. In any case, each set of axes is defined by its organization; linear, circular, elliptic … the angle between two sets being the angle between two of their axes and the interval is the distance between two axes of each set. There exist constant and non-constant intervals.

A profile is defined by its type, its position along the axe and its rotation around it. The type of a profile (section) refers to its form; rectangle, circle … as well as its dimensions. The distance between its gravity center and one end of the axe define the position of each profile. In the case of facets the only possible distance from grid will be along Z axe.

The relation between axes of grid and a section (a profile) can be of two kinds: a surface or better to say the facets of a subdivided surface encountered by grid axes (edges) or a section extruded along the projected axes (edges).

Parameterization of the "Napier University", Edimbrough, Ecosse (figure 7) shows as an example the use of parametric description.

Fig. 7 Example of parameterization of the Grid; "Napier University", Edimbrough, Ecosse

Here the grid is a regular oblique grid with three axes passing from each point. Organization of all three sets of axes is linear and the angular value is about 60°. Intervals of both two axes are approximately constant. The profile is an extruded standard section in the form of circle. Sections at the two ends are identical and there is neither a shift in X nor in Y direction.

The next issue to be parameterized is the category of different assembling methods, which is not for the moment integrated in the model.

Experimentation and Validation

To validate the pertinence of the model (represented in a relational form in figure 6), two kinds of experimentation have been conducted; the model was first used to regenerate the structural volume of fifteen existing projects. As another experimentation, it was also used in an educational experience (CFD workshop) with master students of architecture school of Nancy.

A plug-in developed on the basis of the model was used in both experiments and allowed for the validation of main concepts of the model and their respective parameterization.

The process starts by a "grid" creation, based on the parametric model. The corresponding 2D grid on a non-standard form is the result of a projection. From this the program can generate the structural volume of the received geometry based on predefined profiles. Final step is to create assembling geometry in intersection points of rib network- this step is not still developed.

The associative relation between the grid and the structural volume enhances user's control on the process. Once the grid created further manipulations either on its intervals or on angular value will directly affect the three-dimensional volume. It is also capable of providing the construction dimensioning (2D documents) ready to pass through a CNC machine. The developed plug-in is implemented in Rhino.

First experimentation: regeneration of an existing project:

As explained above the model is here used to regenerate an existing project. The "Kartontheater" (figure 8) design by Hans Ruijssenaars, has been recreated following main entities, concepts and parameters described in the relational model.
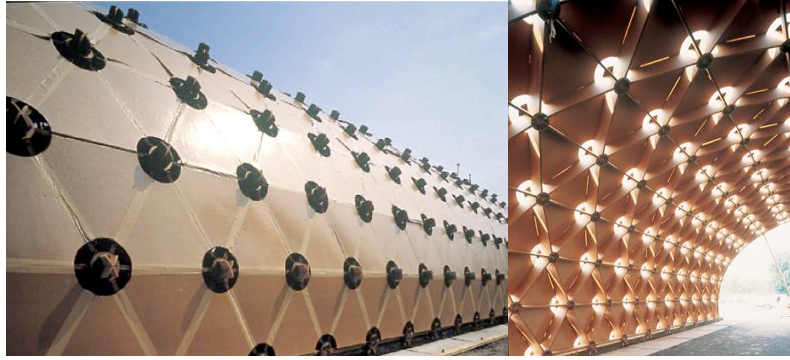
Fig. 8 Exterior and interior views of "Kartontheater", Hans Ruijssenaars

On an initial surface geometry as input, a regular 3-axis grid is projected. This way the structural mesh is created (figure 9). A rectangular profile is then used to generate the structural volume (figure 10).
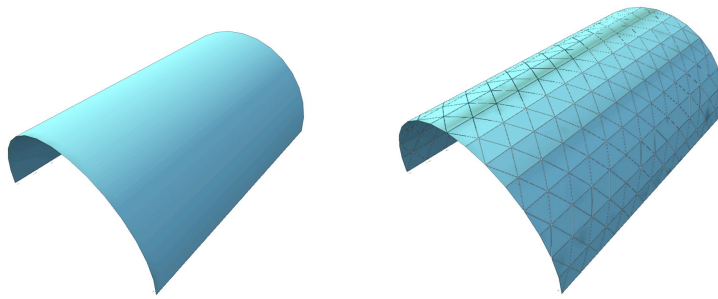

Fig. 9 Regenerating the "Kartontheater", the input geometry and the corresponding structural mesh
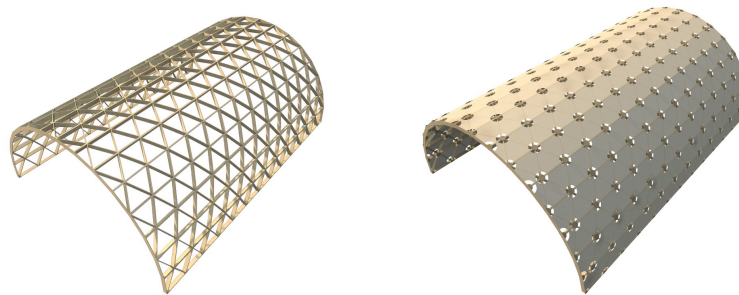

Fig. 10 Regenerating the "Kartontheater", structural volume and the envelope

Second experimentation: CFD

The workshop of Conception Fabrication Digital (CFD) is an annual one-week workshop with graduate (master recherche) students of architecture school of Nancy. The main issue of the exercise is to deal with tree parallel matters at the same time: the process of form generation, integrating construction knowledge and finally digital fabrication.

Students are asked to provide a construction interpretation in parallel with geometric modeling. By means of the typology of the wooden non-standard structures (pilling-up, tessellation) and basic concepts of the proposed model, the students have to question the constructability and transcribe their object in an architectonic reality. Massive wood and all its by-products (BLC, Lamibois, plywoods Panels) are used. Structural and constructional interpretations have been empirically evaluated.

The last stage consists of producing the 2D description of components to make them realize by a 3-axes milling machine or a cardboard cutter (Craft Robot pro). The assembly of models is manual.

Following example (figure 11) illustrates the transformation of a free form geometric model to a construction model. Necessary 2D documents were then prepared and transferred to the 3-axes milling machine. Components were cut out of plywood and assembled to final object (figure 12).
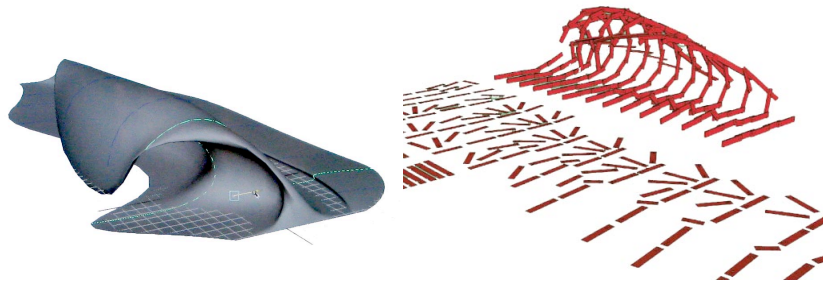

Fig. 11 Transforming the input geometry to the structural volume. Project: Vague ombragère. Students: K Jacquot, Y. Zamagna. Master «AME» 2010
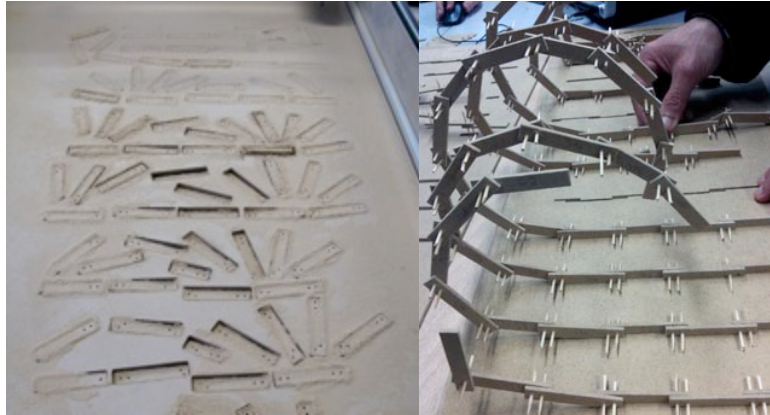
Fig. 12 A 3-axis milling machine is used to cut the components out, which were then assembled to the final object

The passage from the geometric model to the construction model and the generation of the structural volume was assisted by the plug-in. The parametric-generic model, which is proposed to assist the design-construction process, deals with the coupling of architectural and technical aspects of design. However, as the plug-in is still in early phases of development, other software was needed to handle the fabrication phase.

This methodological process is not linear. Because of the cooperative nature of various domains and knowledge involved, it passes through many back and forward stages. Numerous software are used which complicates the management, but the proposed method based on our developed model allows for satisfactory results both in apprenticeship of design-construction aspects and in obtained final objects.

Conclusion

Questioning the continuum of design-construction, the non-standard architecture represents a better positioning of the architecture. Overtaking the current practices - still too much affected by the limits of the modern productivism - Such an approach allows for a revival of the notion of cooperation.

Cooperative design is undoubtedly affected by simultaneously maintaining architectural and technical aspects of design. A sharable model; a model that provides both architects and engineers with the possibility of sharing divers points of view and ideas via a common model,

would enhance the degree of constructability. Such an approach aims at handling design and post-design issues since early stages of design.

Based on such an approach, we try in this work to develop a generic model adapted to the field of timber construction. By integrating different families of wooden structures, the model will assist the transformation of a non-standard surface geometry to a construction model.

Further development of the model consists of integrating parametric assemblies (mortise and tenon …) regarding wooden morph-constructional families. One next concern addresses the coupling of the plug-in with an evaluation environment.

References

1.   Alexander Christopher, Sara Ishikawa, Murray Sylverstein (1977) A pattern language - Towns, buildings, construction: Center for environmental structure, New York, Oxford University Press
2.   Cache Bernard, (1998) Objectile, editions HYX / FRAC Centre. France.
3.   Emmerich David, (1967) Géométrie constructive morphologie, école nationale supérieure des beaux arts, paris, France.
4.   Griffith K, Sass Lary, Michaud D, (2006) A strategy for complex curved building design, sigradi, 10, 465-469
5.   Kilian Axel, (2006) design exploration through bidirectional modeling of constraints, MIT press. USA
6.   Kolarevic Branko, (2005) architecture in digital age: design and manufacturing, Taylor & Francis.
7.   Kocaturk Tuba, (2006) modeling collaborative knowledge in digital free-form design, Netherlands
8.   Lebahar Jean-Charle, (2002) cognition et creation, L'assistance par ordinateur: une technologie d'organisation du travail de conception, paranthesis, paris, PP. 162-188
9.   Menges Achim, (2007) computational morphogenesis, ascaad, 4, PP. 725-744
10.   Natterer Johannes, (2009) Analyse non-linéaire des coques géodésiques multichouches à joints semi-rigides. PhD thesis, Lausanne, 2009
11.   Schiftner Alexander, Jacques Raynaud, Niccolo Baldassini, Peng Bo, Helmut Pottmann, (2008) Architectural freeform structures from single curved panels, Advences in architectural geometry. Vienne 13-16 septembre
12.   Scheurer Fabian, (2008) Size Matters: Digital Manufacturing in Architeture, Dimension, Princeton Architectural Press, New York
13.   Weinand Yves, (2004) new-modeling, presses polytechniques et universitaires romandes, Lausanne
14.   Zaero-polo Alexander, (2004) knowledge of reality, Robustness, 1, PP. 96-100