Advanced Materials Research Vols. 671-674 (2013) pp 2337-2343
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doi:10.4028/www.scientific.net/AMR.671-674.2337

Use of irregular wood components to design non-standard structures

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Keywords : Architecture, Timber structure, Native irregular resources, Environmental foot-print

Abstract. This project deals with architecture and engineering involved in the process of architectural design. Based on native irregular components, it aims at developing an innovative approach in the conception and rationalization of non-standard structures. Contemporary architecture and its non-classical structures require the design of customized pieces. This process which is highly energy and resources consumptive does not always take into account the inherent material properties. This project develops a way of optimizing, in architectural structures, the use of native wood pieces that are not industrially transformed (e.g. boughs) or of reused pieces of carpentry. As a consequence, the ecological footprint of the structures would be reduced.

Introduction

Contextualization of the project

Often associated terminologies of “new structuralism” and “non-standard architecture” refer to various ways of connecting matter, structure and form [1]. Most of the current works are based on design processes dealing with free surfaces to produce at the end irregular structural components [2]. Those works consider the structural component as a result of the intersection of different fields: architectural morphology, structural mechanic, material resistance and fabrication technologies [3]. The non-standard aspect of those realizations is considered as an a priori characterizing the resulting building.

In the present work, we want to put us in an inverse logical sequence in which the non-standard aspect is due to the particularities of the material used as resources. Beyond the doctrinal or esthetical ideas linked to this inverted position, we base our proposition on the valorization of not or barely transformed resources to improve the environmental economy of such a method. Digital tools allow applying a systematic reasoning to a stock of eclectic resources in order to compose an intelligent structure. The materiality of such a work would benefit from the optimized use of elements which are all spontaneously different.

Using barely transformed timber elements was a common practice in vernacular architecture. But Fordist industrialization based on standards has forgotten this approach.To our knowledge, only few works deal with the integration of components at the very beginning of the design process. Among those researches, one suggests the use of native irregular components [4] and one other integrates standard components in the generation of irregular structures [5]

Process and goals

We want here to think about the going and return situation between the reality of physical available resources, the potentiality of the algorithmic design process and the final materiality of the structure. The selected framework is the modeling tool Rhinoceros with its plug-in Grasshopper. Grasshopper allows us to create algorithms capable of generating non-standard geometric structure from existing resources while Rhinoceros enable us to visualize the repartition of the element in the structure. This framework presents the advantage of easy interaction for the designer and also allows modulation of the final program.

The first part deals with the election and digitalization of the elements constituting the resource stock and consists in determining and analyzing the characteristics of the resources at our disposal. As a result, we obtain a digital model containing the parametric data of each element. The second part aims at finding with an algorithm an intelligent position in the structure for most of the elements of the resources stock. As a third part, we suggest how to evaluate the mechanical behavior and how to reach the engineering feasibility of the propositions formulated by the algorithm.

Caracterisation of the native components

Election of the components

This article presents an integration of architectural, structural and environmental aspects in a global algorithmic process. The use of available resources in their initial state limits in the same time matter waste and energy consumption. That appears nowadays as a considerable stake in the field of sustainable practices. The current study is especially oriented on the treatment of boughs which could have different sizes (diameter from some centimeters to several tens of centimeters) but also could be declined to reused pieces of carpentry.

Nevertheless, that implies a real increase in the complexity of the design and realization of the structures. Barely transformed elements present irregularities in their form, dimensions and mechanical behavior. As a consequence, the digital and parametric model needs to be able to furnish to the algorithm all the selected characteristics of the elements from the resource.

Valorization of the particularities through a parametric model

We develop a parametric model able to fit to a huge diversity of potential structural elements. This model includes on one hand the geometric data of the main fiber of the element and on the other hand the geometric data of the section along this fiber. With such data, the algorithm will be able to dispatch in an ingenious way the resources in the structure. The idea is to use the intrinsic particularities of the resource element during the design process.

The model is made of a main fiber with branches disposed along. Main fiber and branches can be either curved or straight with a profile assigned to it. The profiles allow to analyze the mechanical behavior of the structure and to take it into account while the structure is being constituted. Then, the main goal is to use a natural resource with its actual singularities (curve variation, profile variation…).

Finally we get a model adaptable to various kinds of resource elements. It will supply the following algorithm with the geometry of each element and with the repartition of matter along this geometry. We limit our case study to linear elements in which length is huge in front of other dimensions of the element. The model is made of two parts: one line part with main fibers and one volume part with extruded profiles. Volume part associated to a mechanical coefficient based on the wood characteristics will inform about structural performances.

Digital treatment of the physical stock of resources

The digitalization process consists in identifying interesting points on the element in order to set the linear and angular parameters to supply the digital model. Spatial metrology presents some difficulties but the use of a laser scanner or an articulated digital arm is efficient to establish a cloud of points from the original element. In a second time, parameters of the digital model are modified still the model fit the cloud of points.

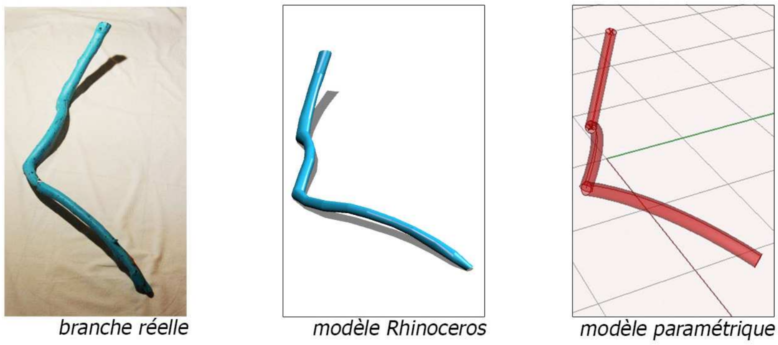

Fig. 1 Branch Original bough, model with digital arm and simplified parametric model

Positionment of the components

Process

The stake of this work is to identify and isolate elementary constructive reflection steps in order to elaborate the algorithm. The designer reasoning to elaborate a structure from irregular wood components could be subdivided in elementary operations repeated along a process. This is the idea of the "log cabin" made of all different pieces of wood, but above all yet available, imposed and not imagined. We have translated in an algorithm the logical sequence realized by the person who is raising his hut taking into account stability and mechanical resistance rudiments.

The implementation of the resource as a structure needs first a design intention. This intention will be traduced as a tridimensional referring surface associated with density of distribution parameters and eventually special points (e.g. support points). The functional, formal or mechanical ideas aimed by the designer could be determined by the three previous parameters. We limit our research to approach a referring surface but the process could be extended to referring line or volume. Also we will develop a solution including an intermediate step in which the referring surface is traduced as a constructive pattern made of segments. This pattern introduces principal directions which will be a kind of armatures. We could also take into account ideas of useful volume in the definition of the designer's architectural desire.

The optimized disposition of a resource element on the referring surface constitutes the first part of the reasoning. Two ways of doing it were developed: first an exhaustive exploration and second a 'winner-take-all' exploration. The first method consists in generating populations of possible dispositions for one element and looking for the more interesting situation according to designer's criteria [6]. The second method takes into account the designer's criteria as soon as a position is generated by the algorithm and then there is immediately evaluation of the position. If the position is interesting, the algorithm keeps it and passes it to the following resource element. If not, a new position is generated and evaluated. The second method presents interest in terms of memory and velocity in spite of less precision.

The following points present two variations of the generative algorithm.

Exhaustive research for an optimized disposition

The first way of proceeding consists in the generation of populations of possible positions linked to repartition points. Those positions are spread on the referring surface and then submitted to a selection according to design requirements. The disposition could be constraint by singly points or couples of points named *destination points*.

After constituting the population of possible position for an element, the algorithm proceeds to the selection of the optimal position according to three successive design requirements: belonging to referring surface, spreading density and proximity to the referring surface.

The operations and tests presented above constitute algorithmic entities to duplicate and connect ones to the others in order to obtain the whole generative algorithm. After defining the referring surface, the combination of the elementary entities will establish the designer's building strategy. The algorithm proceeds to a linear treatment of the resource elements, in consequence the designer has to organize the list of those elements furnished to the algorithm. This organization could be based on the geometric criteria of the elements: bulk, profile, mass... according to the intentions.

One way of proceeding is to dispose successively all the elements in the structure looking for one or two anchorage points on the elements yet constituting the structure. Another solution is to do differentiate phases in which the disposition does not take into account any anchorage point, look for one anchorage point or look for two anchorage points. The resource elements' list assigned to each phase is defined in consequence: first larger elements as framework and then smaller elements as connections. For both solutions, the resulting structure will be a network of resources elements as a bird's nest.

Sequential research for an optimized repartition

The second way of proceeding is to develop a structural pattern on the referring surface and to fill it with elements from the resources stock. The constructive pattern can be inspired of conventional techniques as grid of arches or can be more specific [7]. When the designer has established a constructive pattern made of segments on the referring surface he has defined, the algorithm is used to find resource elements able to perform segments of the pattern fitting at the same time the referring surface.

To link structural resistance requirements to the process, the pattern is submitted to a loading case with hypothesis about connections and supports in order to watch the mechanical forces repartition. We attribute a coefficient to each segment of the pattern due to its solicitation. That will be put in connection with the resistance of the elements as described part 2.2.

We deal with the following inputs:

- List of available resources and resistance coefficients associated.
- List of pattern's segments and resistance coefficients associated.
- Referring surface.
- Percentage of difference between resistance coefficients.
- Maximal distance tolerated from referring surface.

As outputs, we get the list of the elements disposed on the referring surface. This list integrates all the characteristics of the elements through the parametric model presented part 2.2 and the data referring to the spatial position of the elements in the structure.

The filling of the pattern's segments is sequential: resources elements are tried successively on one segment until one perform the segment and fit the referring surface. An element performs a segment when it is long enough and gets a percentage of difference between resistance coefficients acceptable according to the input. We consider that an element fits the referring surface when all its points are situated at a distance from the referring surface smaller than the input.

The algorithm use *for loops* associated to conditions (percentage of difference and maximal distance) to attribute elements to the pattern's segments. When the algorithm find a couple element/segment which perform the previous conditions, corresponding item from each input lists is deactivated and the algorithm go to the next resource element.

Finally, the algorithm proposes different structures due to little variations of requirement conditions. In case of a percentage of difference too small or a proximity requirement too high, the algorithm will propose an incomplete structure, leaving some pattern's segments empty where any resource element still available suits.

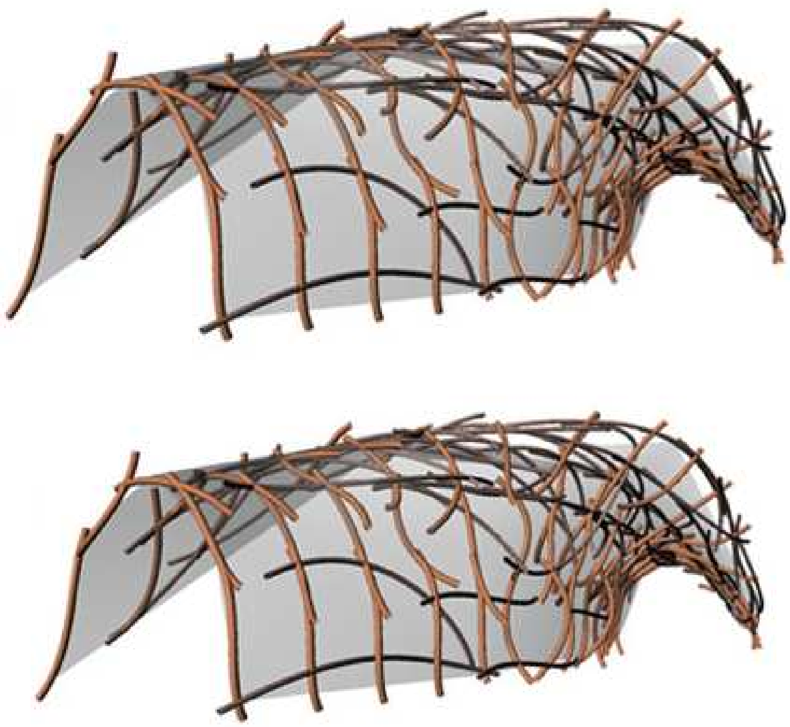

Fig. 2 Exemplary structure obtained

Mechanical behavior and engineering choices

When the digital model of the structure is obtained, the principal stake is to assure the technical feasibility and to allow the physical concretization of the virtual project. The intermediate step of using an algorithm to design a structure made of irregular components implies to be able to reconstitute the configuration and identify each element on the building site. We use the algorithm to extract the curvilinear abscise of each connection point identified on the elements. Also, the following points describe how we aim at more precision in the connection points, how we evaluate mechanical resistance and which solution could be considerate for the envelope of the whole structure.

Nodes between the elements

When the elements are situated in the space in order to constitute the structure, it relates to do the connections between them to give the structure stability, rigidity and resistance. Another algorithmic treatment is realized to adjust the positions given by the previous algorithm. The previous algorithms dispose the elements according to their main fiber, as a consequence, nodes are punctual.

The optimization of each position aims to take into account both the section of the elements and the constraints due to the connecting system. This process is repeated successively on each structural element until we get a coherent configuration for each node preserving the general aspect of the structure.

The manipulation consists in moving the element by rotation around a first node to give better configuration to a second node of the same element. Then, the manipulation is repeated with a rotation around the second node, memorizing the new position, to give better configuration to the first node. We keep the nodes on a connection axis normal to the referring surface. This connection axis could become the axis of a threaded stem or other connecting system.

Finally, several way of realizing the nodes between the elements are considered: threaded stem associated with spacer or wood slotting together, swivel scaffolding elements [8], flexible links. The election of one kind of connection system must be considerate according to the developed pattern to manage the structural consequences.

Evaluation of the structure with a finite elements analysis

The propositions of structures formulated by the algorithm integrate mechanical requirement because of the resistance coefficients but do not guarantee any mechanical performance. The treatment following the algorithmic process is to evaluate with a numeric tool the mechanical resistance of the whole structure. This evaluation is realized according to the hypothesis made about the connections, the supports, the geometric and mechanical characteristics made about the components and the loads applied.

The algorithmic process turns out to be efficient to get quickly the data needed to realize a finite element analysis of the structure in mechanical software such as Karamba (plugin for Grasshopper), RDM6 (software of the University of Le Mans) or Castem (CEA's software). In consequence, the designer is encouraged to produce various possible structures he will evaluate and among which he will finally choose one.

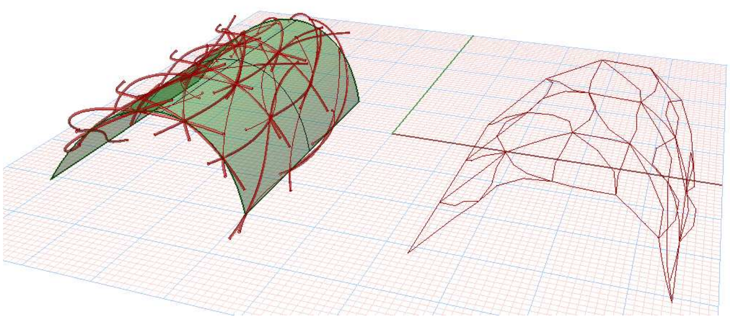

Fig. 3 Digital mockup and layout for wired calculations

Envelope which form the outer skins of the structure

Here again, the digital model turns out to be useful to elaborate the envelope of the structure. Indeed, all the spatial coordinates are available to proceed to the research of minimal form and establish the geometry of a structural textile able to fit the structure. Different method to find those forms could be employed as the discretization in cable network or Surface Constraints Density method [9].

However, such an envelope creates geometrical constraints which have to be integrated as soon as the definition of the formal intention traduced in the referring surface. Also, there is a modification of the forces applied to the structure due to the tension of the textile and the mechanical behavior in case of wind or snow changes. Those new data have to be incorporated in the evaluation presented part 4.2.

Conclusion

The idea developed in this paper is to take into account matter and structure from the first stages of the formal design. The process aims at generating from available native wood elements the maximal constructive ability. Also that aims at limiting the industrial transformation operations in order to restrict the ecological footprint of the structure.

The complexity induced from the introduction of an irregular resource is solved by an algorithm operating with the digital models of the elements and allow exploring various configurations replying to the designer architectural intention.

Prospects opened here in terms of digital design anchored in a process of existing material valorization demonstrate potentialities gifted by early integration of structural and environmental questions in the project.

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