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Automatically adapted metal connections by CAD / CAM technology to the irregularities of the roundtimber

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ABSTRACT
The round wood, material whose need for improvement is minimal, presents itself as an efficient material for use in buildings due to its physical - mechanical properties, functional versatility and respect for environmental requirements. They are characterized by unique pieces, with tapered shape and wavy longitudinal axis, dimensional irregularities that hinder junctions and enhance the importance of connections in architectural compositions. Without the processing of woodturning that keeps the diameter of the logs constant, the joints need to be adjusted to the formal irregularities of each log by hand. With the parametric modeling and the digital fabrication, this work suggests the automatic modeling of connections adapting them to the actual measurements of the logs, reducing material losses, resistance and adjustments in the process.
Keywords: articulation; parametric modeling; round wood; scanning.

I. INTRODUCTION

The debate on sustainability leads to the search for effective constructive solutions, with low material waste and low power consumption. [1]. In this case, the round timber stands out, it is a material that requires minimal processing. [2].

Each trunk of round wood is a unique cone shaped piece, with longitudinal wavy axis. The form variation of the stem: taper, straightness and flatness [3], defines dimensional irregularities that hinder joints and enhance the importance of the connection in architectural compositions. The generation of architectural forms and spaces will depend on combined strategies that consider the type of junction between the parts. [4]. The connections help obtain complex shapes with dimensions of relatively limited parts. [5].

Most joints require adjustments by the use of notches in the logs to fit the contact surface. Metal connections are made smaller than the average diameter of the logs. When the said diameter is larger, logs are chopped, and when it's smaller, there is no slack along the metal part. The processing a tapered log down to a uniform log standardizes its diameter, but reduces the resistance to bending. [6].

Relying on new technology [7], this study suggests the modeling of connections to allow the adjustment of actual measures of the logs, reducing loss of material, resistance and adjustments during the construction. With parametric modeling and digital manufacture, connections can be individualized for each junction point, considering the dimensional irregularities of each log. Based on the study by Ino (1992) [8], which measures the log manually to extract form data, the sections approximately every 10cm, to verify the form variation of the stem and get dimensional data. A process that encompasses scanning and specific programming allows these measurements to be automated and to contribute the increase in the automation in the civil construction, a sector that slowly adapts to this technology. [9].

Through the concept of "generic connection" [10], it is possible to explore multiple solutions of metal articulations adapting to the various positions that allow a log to be turned into architectural composition. This study develops the concept of generic connection adapted to the actual measurements of the logs and will be divided into 3 chapters. In the first chapter, materials and methods will be explained, the second chapter will discuss the given results, and the third chapter will present the conclusions. These items are described as follows.

II. MATERIALS AND METHODS

Three eucalyptus logs were used, placed in autoclave, donated by *Empresa Postes Mariani*, located in Guaiba-RS-Brazil. All the parts are measured as follows: 1.16 m, 1.50 m and 1.60 m. All were requested and supplied with the average diameter of 10 cm.

The proposed methodology for generating connections adapted to the irregularities of roundwood is divided into: 1) Scanning - describes the necessary process to scan the logs and insert the scanned roundwood into the computer, 2) scanned roundwood and dimensional data - describes the process used to transfer the logs scanned to the CAD (Computer Aided Design) system as well as the process to extract specific dimensional data, 3) Generic connection and scanned roundwood - describes how measures of logs feed the model of generic connection and generate connective alternatives adapted to the irregular roundwood. The methodology illustrated in Figure 01, is detailed below.

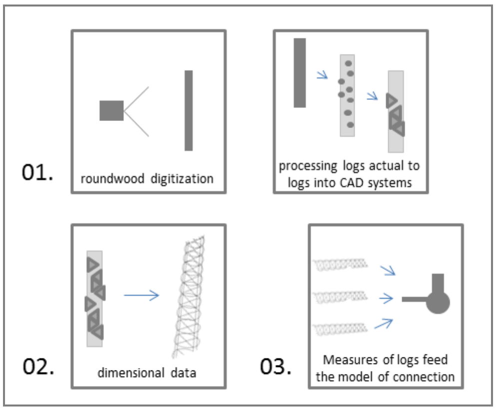

Figure 01. Scheme of the stages of the methodology.

2.1. Digitization

To achieve the dimensional information of the roundtimber without needing to measure piece-by-piece, the roundwood has been scanned, and the data has been processed directly on the computer. Three-dimensional scanning consists of capturing data from the surface of a given object, defining the location of points in space. Its Cartesian coordinates represent each point, and acquisition of this " cloud of points" represents the geometry of scanned objects. [11].

There are many methods of digitization: scanning, laser scanning by white light, Photogrammetry, among others, whose time, accuracy and cost vary the method chosen. [12]. In civil engineering, the recognition of the application of this type of technology in the industry [13] grew, as well as in the lumber market that uses scanning systems to measure the volume of trunks and to ensure greater accuracy in its trading market in many countries. They guarantee more accurate data compared to data obtained by manual measurement. [14] [15] [16].

In this study, the roundwood was scanned using the scanner Konica Minolta Vivid 9i. This mobile device that uses the triangulation process to "capture" the images, provided by Design and Selection of Materials laboratory (Design e Seleção de Materiais), LdSM, Universidade Federal do Rio Grande do Sul.

Each scan performed by this machine captures part of roundtimber. For every 1 meter length of log, around 20 takes have been captured, generating clouds of points in computer through the scanner's own software, polygon editing tool.

These clouds were handed over to data processing software, Geomagic Studio 10, provided by the company Geomagic. In this software, the images were combined together using three reference points in each of two images. These points, indicated by the operator, are superimposed by the software that adjusts images and combines them. The generated cloud was smoothed by eliminating duplicate points and converted to mesh, mesh composed of triangles. The file was saved in STL format. This conversion was necessary in order to enter the digitized logs in Rhinoceros by the software company McNeel. These steps are illustrated in Figure 02.

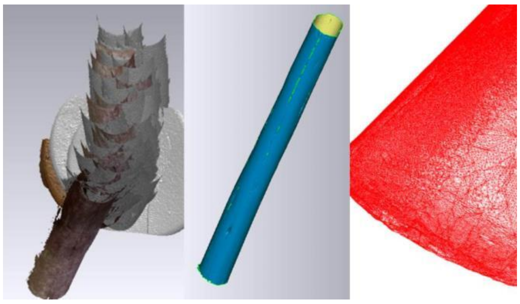

Figure 02: On the left, various images from the piece that were joined to form the log scanned in the center. The image on the right shows the log transformed into mesh.

To facilitate the assembly of many clouds of points, the pieces of roundwood were kept together by elastic bands, previously numbered and each one with a different color, distributed by its length, every 30 cm, to suit the longitudinal extent of each scan. The numbers 1-5 in each elastic band guarantee vertical coverage, which captures two numbers in each scan. (Figure 03). The clouds were easily put together, combining the numbers and the colors.

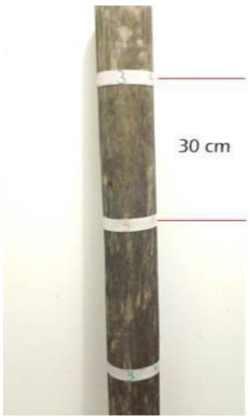

Figure 03: Log piece with rubber band every 30 cm, ready for scanning.

2.2. Digitized logs and dimensional data

After being transformed into mesh, the scanned logs were processed in Grasshoper, developed by David Rutten and Robert McNeel & Associates, a plugin integrated into Rhinoceros, program compatible with CAM technology (Computer Aided Manufacturing). [17].

As the processing of each digitized log becomes slow due to the amount of information provided by the mesh, and it makes it harder to manipulate in CAD (Computer Aided Design) software, we opted to obtain specific dimensional data from virtual objects.

Based on the study by Akemi Ino (1992) [18] who created a method to measure the pieces manually and to extract data that determines the formal characteristics of logs and formal variation: taper, straightness and flatness, a cross section was extracted approximately every 10 cm dividing each piece into specific number of sections. For each cross section, two mutually perpendicular axes were placed, Dxx and Dyy, defining a larger diameter and a smaller, since they both have different dimensions between them (Figure 04).

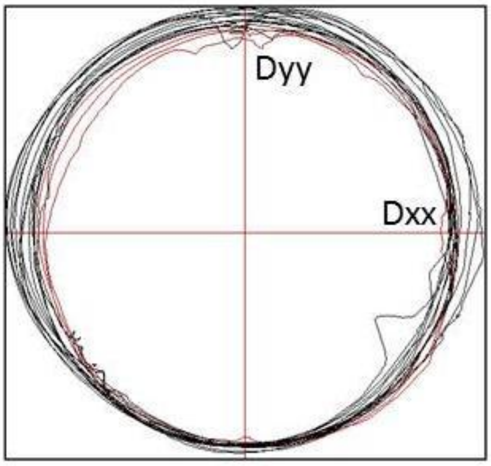

Figure 04. Cross-sections of the log extracted by programming in grasshopper. The horizontal and transverse axis in the middle of the piece, *Dxx Dyy*.

Dimensional data were obtained by using the resources within Grasshopper, beginning with Bounding Box command, which defines a box around the log, the maximum size of its outer edges (Figure 05). To run this command, it was necessary to rotate the log, aligning it as parallel as possible to the plane x, y.

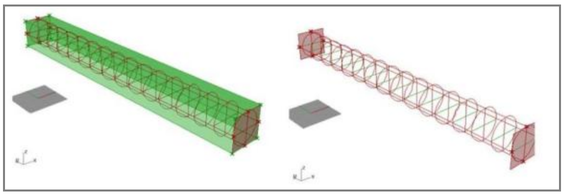

Figure 05: On the left, the box is displayed in green around the log. On the right, the sections were made in scanned log.

The sections were obtained through the intersection of the plane defined in the software, with the scanned log. The longitudinal and transverse axes were drawn on the outer faces of the box. These axes were copied to all sections, and the excess section was excluded. Two diameters for each section were obtained, dividing the circumference into quadrants.

With the *back* command, sections, diameters and longitudinal axis were inserted into Rhinoceros, i.e., to be created as graphics, as the Grasshopper connected to the Rhinoceros allows only viewing what is being programmed.

2.3. Generic Connection and digitized logs

Sections and diameters extracted from the digitized logs turned into another digital file that has been brought into Rhinoceros, served as a basis to feed the generic connection programmed in Grasshopper.

In the generic connection proposed by Teribele (2012) [19], the position that the log assumes the architectural composition is considered. Data such as inclination and angulation of the log influences the shape of the connection, divided into components according to the function that performs at the junction as shown in Figure 06.

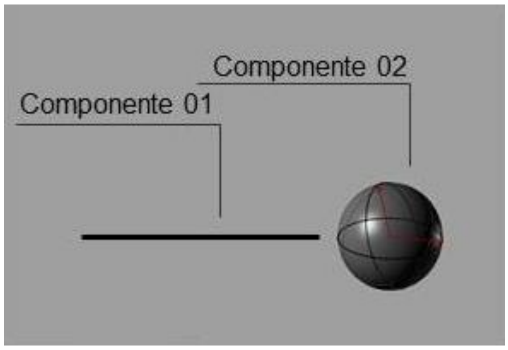

Figure 06: Generic Connection that connects outer edges of log. Source: Teribele 2012

The component 02 is characterized as one in the central node that separates the logs when it is present. For being nonexistent, the roundwood is forced to lean against each other, making them to carve to mold contact surfaces.

The component 01 is effectively fixed to the log piece and may use different solutions of metal connection that served as a model for this component as shown in Figure 07.

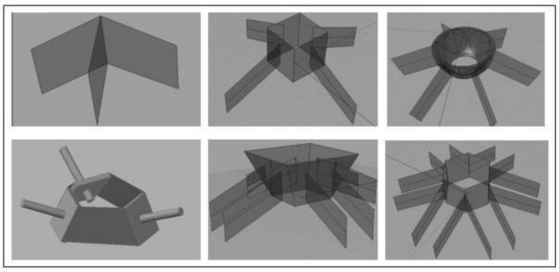

Figure 07: Generic Connection with different vocabularies for component 01 and 02. Source: Teribele 2012

In this article the component 02 has generically created using the average diameter of the logs while the component 01 is modeled as double outer plate, the inner plate and curved plate. For each solution, a specific type of measure is necessary to feed the generic connection. For outer plates and inner plates, Dxx or Dyy diameters were used, extracted from the sections as shown in Figure 08.

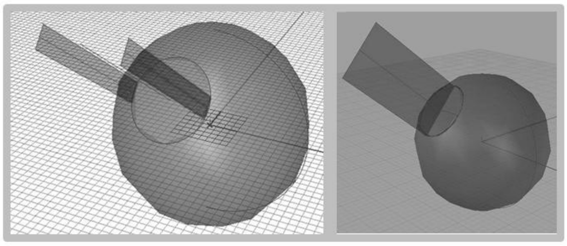

Figure 08. Modeling of outer plate and inner plate.

As the x and y diameters of each section are different from each other, the dimension to feed the component 01 was programmed to receive the smaller diameter of the selected log. The selection is made between Dxx and Dyy diameters, from the base and the top of each log. Figure 09 illustrates this programming.

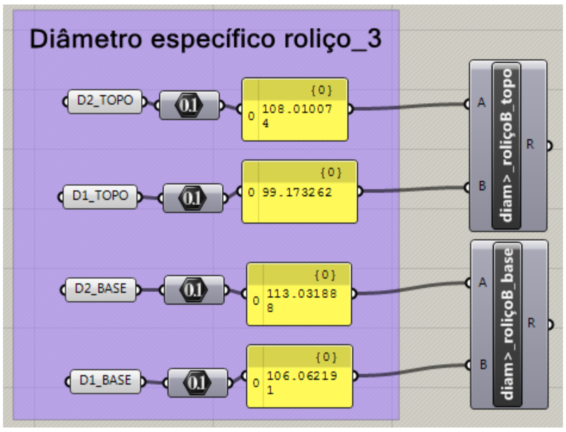

Figure 09: Programming done in *grasshopper* to select the smaller diameter of the section, which fits into Dxx and Dyy the diameter of the base section and the top of each scanned log.

The curved plate was modeled according to the curvature of log. Carrying the sections extracted from digitization, the "loft " (grasshopper) command was used to join these curves and to create a surface, a cylinder forming the irregularities of the material. In this case, lateral notches may be exempted. Figure 10 illustrates an example of this proposed structure. Figure 11 shows a variation of this vocabulary where this curve was faceted.

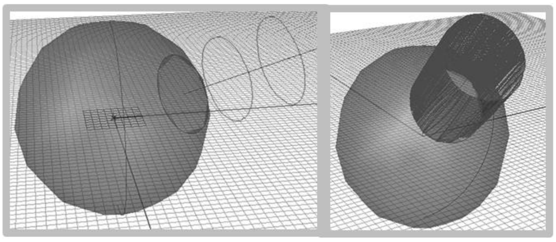

Figure 10. Modeling of curved plate. Image on the left shows the sections extracted from the digitized logs transported to the connection. Right image shows these sections together.

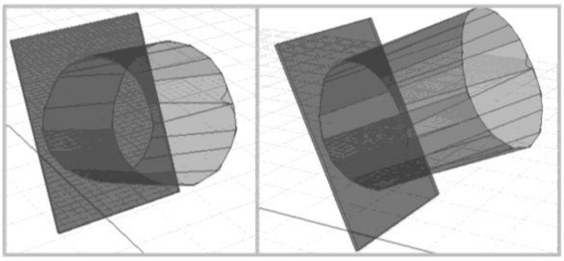

Figure 11. Modeling of a Plate faceted curve.

A connection model was tested using 3 units of the component 01, where each one of them has the dimension of a specific log, as illustrated in Figure 12.

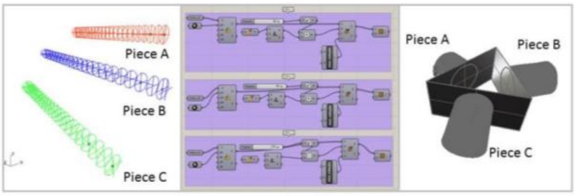

Figure 12. Connection with 3 units of the component 01, where each one of them has been modeled with measurements of a specific log.

III. RESULTS AND DISCUSSION

3.1. Scanning

In the scanning phase, the scanner used in the study required editing from the clouds of points, which was facilitated by the use of previously numbered rubber bands. There are other types of 3d Scanning equipment that can speed up the process, such as the white light scanner, which grouped the images automatically using its own software. The digitizing processes that measure the volumes of logs for sale are another possibility as they are specifically prepared to scan the material in question.

3.2. Dimensional Data

The obtained data allows modeling the connection digitally with the actual measurements of the pieces, but it was noted that it would be necessary to mark the quadrants of logs before scanning. This facilitates the rotation of the scanned piece as well as the subsequent attachment of individual connection to the log, for which it is intended.

3.3. Connections

The models used are part of the repertoire of the architecture with roundtimber, and their characteristics of fixation lead to some sort of notch in the log: the inner plate, inner court, threaded rod, drill, flat outer plate, trimming the side of the log. The knowledge of the exact measurement of the diameter of the roundwood can reduce the amount of trimming, as currently executing of metallic connections is based on the average diameter of the roundtimber.

Customized joint can prepare the log in advance, and in the study, solely to fit the connection, facilitating and speeding the implementation and decreasing craftsmanship. The cutouts and holes needed for attaching the connectors can be planned and executed in a precise way.

It will need more time to prepare and develop the project and less time for its execution, as the CAD / CAM technology gathers the information for the construction directly from the project. [20].

The connective alternative of curved plate customized to the log is an alternative that does not require trimming. Only the hole for fixing screw will be needed, and this can also be provided in the project and be done prior to the scanning of the logs. Studies aimed at a connection to curved plates of ¼ circle adapted to the sections of the log can extend formal variation of articulation automatically adapted to the irregularities of roundwood.

IV. CONCLUSIONS AND FORTHCOMING STUDIES

This study demonstrated the ability to plan the connection to the exact measurements of the logs that will be put together. As each log is different from one another, the metal connections should be customized for each junction point. This may contribute to the decrease of adjustments and notches in the constructions.

The scans used for commercial timber can help improve this methodology by optimizing the scanning process. A pre-programmed computer system would give the necessary data for making each junction quickly and accurately. To be able to join the correct logs at the time of execution, keeping the relation between connection and articulation, it is directed for development of methodology that relates to the digitized logs with real logs.

There was a need to keep an eye on the longitudinal and transverse axes, quadrants, at the time of scanning, so that the data extracted in the software match the reality, to be used in study. The level of the appropriate custom connection with real log and the 3D model in the software should be verified.

The logs could be drilled prior to scanning for correct insertion and location of the holes in the plates before scanning the pieces. This may facilitate the correct fixation of the modeled connection as well as the connection of it, since it would detect that in software.

Another possibility is to analyze variations in the integrity of the logs to verify that the actual longitudinal axis interferes with the architectural composition. Currently compositional study considers the longitudinal axis rectilinear, without variations present in the pieces.

The use of CAD / CAM technology in the architecture with roundwood may implement the execution of connections, decreasing the need for adjustments in the process. It encourages bolder proposals for architectures with this material, as it will facilitate the implementation of the unions.

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