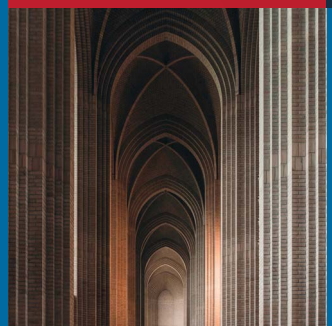

# 3MURI
## VAULTS

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STRUCTURAL SOFTWARE

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# 3Muri Vaults

The software 3Muri Vaults allows you to design and verify any vaulted structure, ensuring an approach consistent with the most recent technical regulations and guidelines for the built heritage.

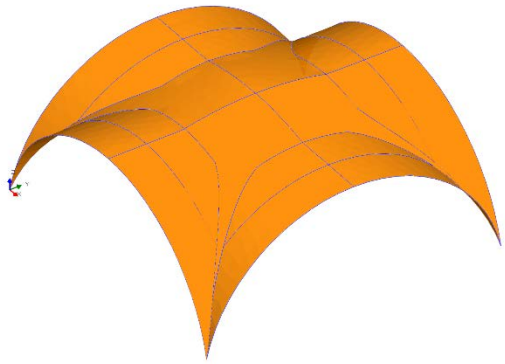

*Fig. 1 - Star Vault*

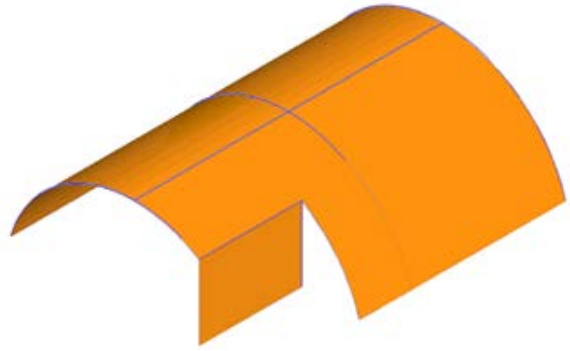

*Fig. 2 - Lame Barrel Vault with little wall*

3Muri Vaults presents a simple work environment in which it is possible to create and check vaults. In each project work, multiple vault models can be created.

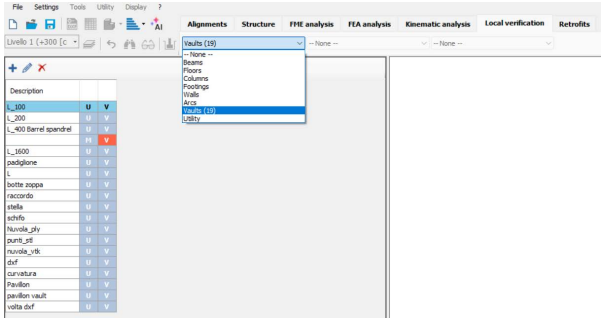


*Fig. 3 - Working environment of the 3Muri Vaults*

The 3Muri Vaults work environment presents an intuitive graphical interface composed of the following 5 sections that guide the designer from the definition of the vault characteristics to its analysis: Geometry Input, 3D, Added Entities, Features Input e Analysis.
The 3Muri Vaults's calculation engine, called MADY, was developed by the research group of the University of Florence formed by Prof. Massimiliano Lucchesi, Prof. Nicola Zani and Prof. Barbara Pintucchi.
MADY is a finite element code that uses the displacement method and can perform force-controlled static analyses.

# Geometry and loads input

The geometry input mode of the turned surface can be done in two ways, selectable from the appropriate menu:

1) 3D point cloud: the geometry of the vault obtained from the laser scanner survey can be imported using a point cloud, which will also form the calculation mesh. The formats supported for import are: *.ply, *.stl, *.vtk.

2) 3D Modeling: The designer defines the geometry in plan and assigns the dimensions of notable points. The import of DXF files and the management of dimensions and arcs, through the toolbar, is also supported by graphic supports.
The three-dimensional surface of the vault is generated automatically. The 3D modeling of the vaulted surface is obtained by assembling the following elementary objects present as icons side by side on the mask toolbar: vaults, masonry panels, spandrel walls and holes. After choosing an object, you draw its plan by clicking in the graphics area and finally you assign a unique name to the created object.
The basic vaults are listed in the “Vault” icon menu and are as follows: Barrel Vault, Sail Vault, Cross Vault, Pavilion Vault and Lunette.

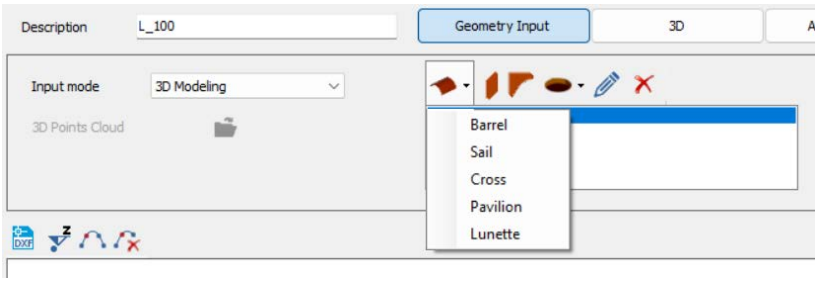


*Fig. 4 - Geometry Input section mask and elementary vaults menu*

The different vault geometries listed can, therefore, be enriched with the addition of structural elements such as stiffening bars, internal wall panels, and circular or polygonal holes, allowing the creation of complex structural configurations.

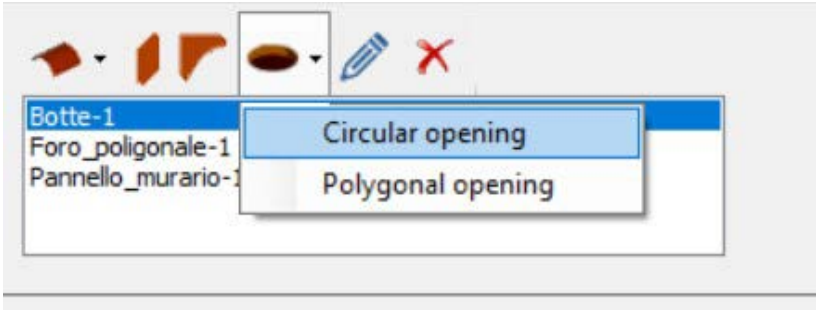


*Fig. 5 - Geometry Input section mask and vault hole types menu*

The project can be particularized by also defining the geometry of the edge of the vaulted surface as a pointed arch, an elliptical arch, as in the figure:

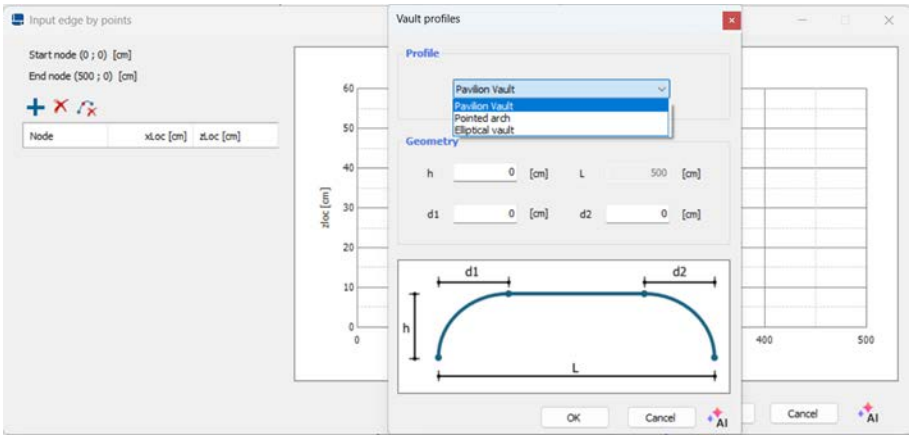


*Fig. 6 - Input mask for the coordinates of the points of the vault surface*

or create the profile of a barrel vault with pavilion heads, as in the figure:

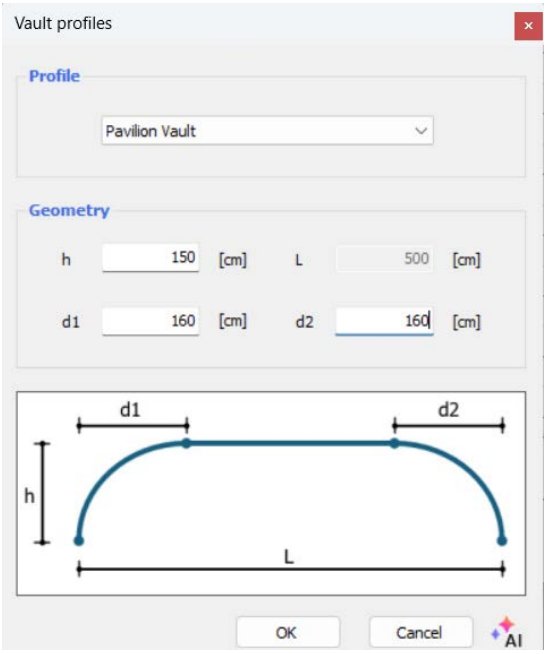


*Fig. 7 - Insertion mask of the pavilion vault profile on two sides of the barrel vault*

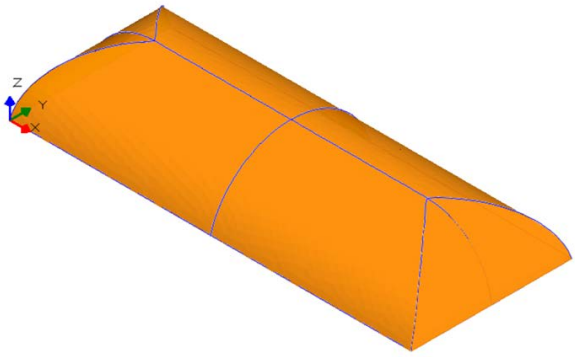


*Fig. 8 - Barrel vault with pavilion ends*

La sezione 3D permette di visualizzare la rappresentazione grafica tridimensionale della volta modellata e della sua mesh.

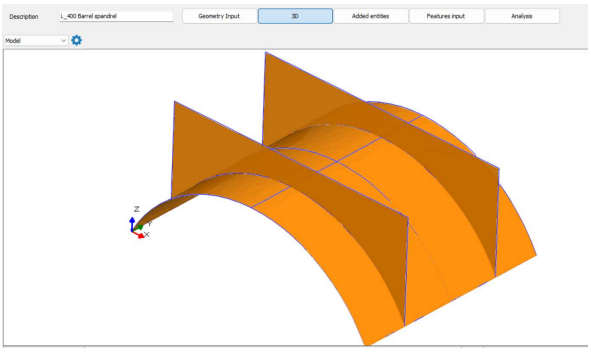

*Fig. 9 - Three-dimensional viewing window of the modelled vault*

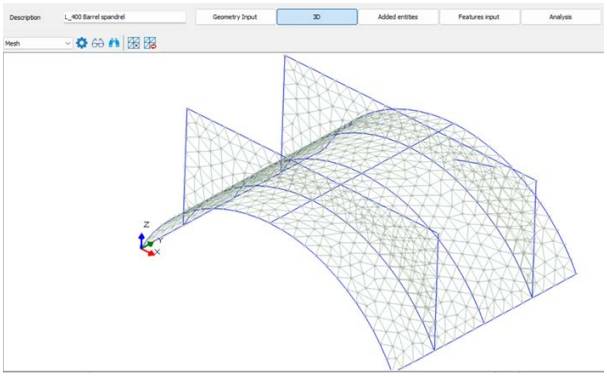

*Fig. 10 - Three-dimensional viewing window of the modeled vault mesh*

By combining the elementary objects, 3Muri Vaults allows you to model, for example, the vaulted structure obtained by connecting two barrel vaults, the L-shaped barrel vault and the Mirror vault, as in the following figures:

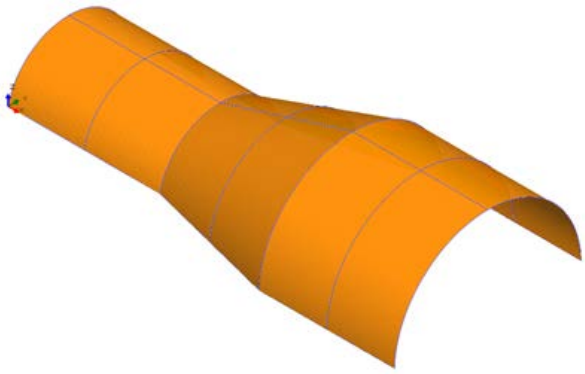

*Fig. 11 – Two connected Barrel vaults*

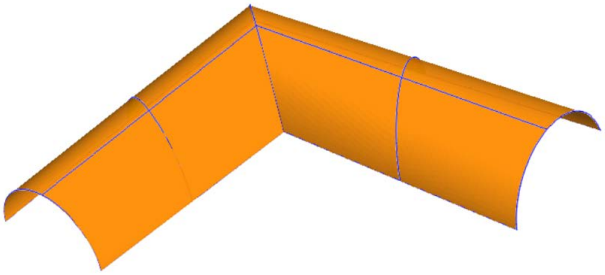

*Fig. 12 - Barrel vault with L-shaped plan*

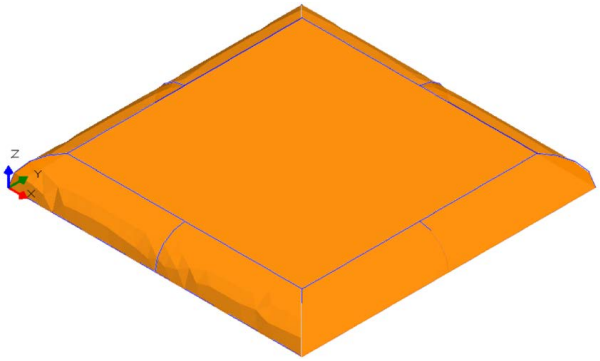

*Fig. 13 - Mirror vault*

Professional user can assign different mechanical characteristics, thicknesses and loads for the different areas of the vaulted surface in the Features Input Section, as shown in the figure.

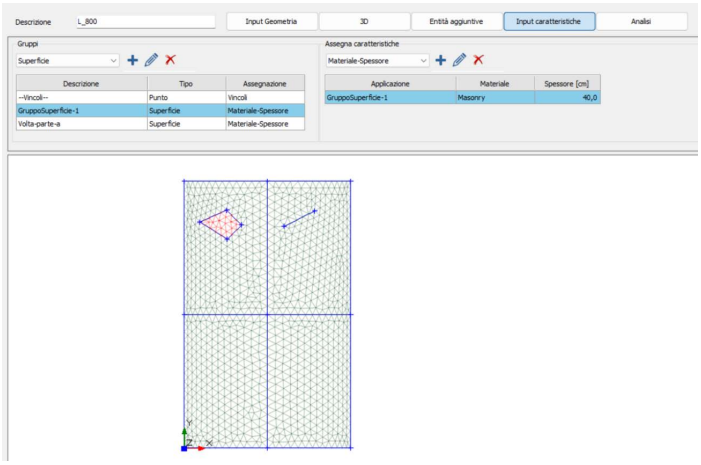


*Fig. 14 Sezione Input Caratteristiche*

It is also possible to model non-point supports for the cross vault, as in the figure:

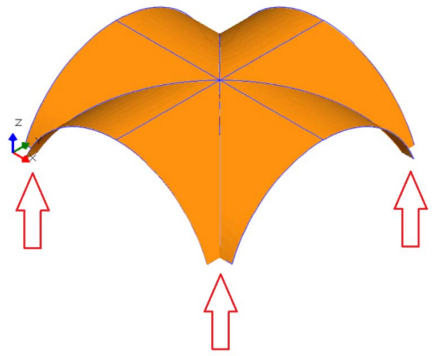

*Fig. 15 - Cross vault with non-point supports*

In addition, 3Muri Vaults allows you to automatically consider the load due to the weight of the filling placed above the vault by entering the following data.


*Fig. 16 - Vault filling data entry mask*

This load is a critical aspect in complex vaulted structures and is often difficult to manually compute and accurately insert into the model.

Professional user can assign different types of constraints at any point of the vault, as in the figure.

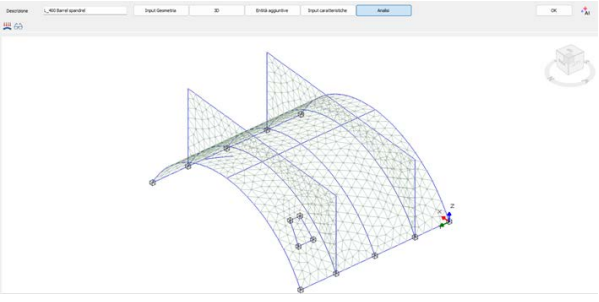

*Fig. 17 - Three-dimensional visualization of the vault mesh with constraints*

# Analisi della superficie voltata

MADY was mainly developed for masonry-like materials, for which a constraint on tensile stress (i.e. zero tensile strength) is expected, while compressive strength can be considered either finite or infinite.

Consequently, analyses can be performed that consider the nonlinearity of the material, in which only static loads applied to the vault in increments (load steps) are considered.
The FEM approach allows to calculate in detail the entire structure of the vault with the static analysis that simulates the structural behavior.

*Fig. 18 - Three-dimensional visualization of the displacements of the mesh nodes of the turned surface after the analyses.*

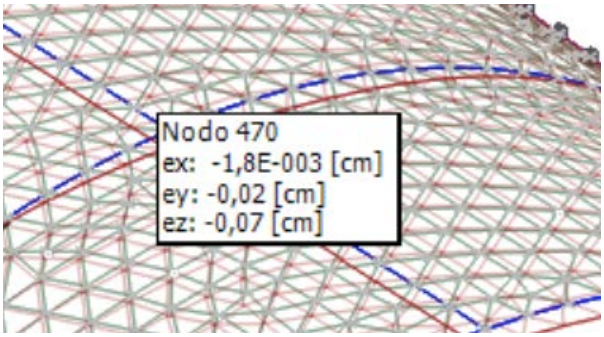


*Fig. 19 - Viewing the results of node displacements by moving the mouse on the 3D surface mesh.*

The linear static analysis of the vaults, on the other hand, carries out a geometric check and a check of the compression resistance of the vault.

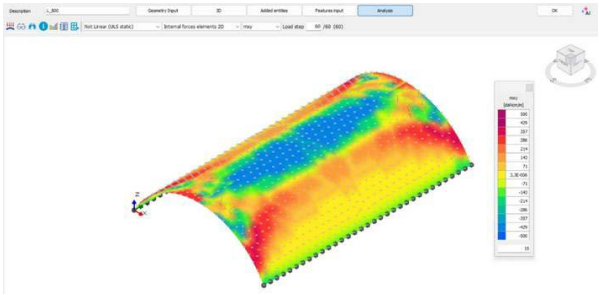

*Fig. 20 - Graphical display with color map of linear analysis results in the Analysis Section*

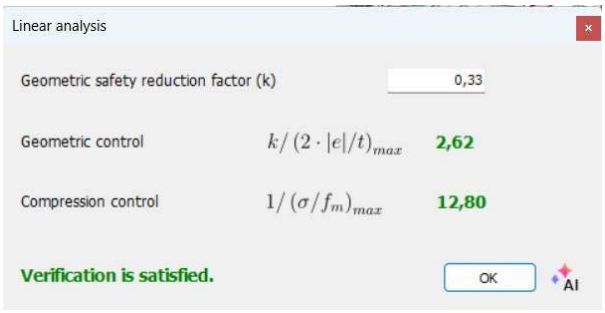


*Fig. 21 - Summary sheet of the results of the linear analysis*

If the verification is carried out in a non-linear regime, 3Muri Vaults, through its advanced calculation models, represents the damage under increasing loads and evaluates the safety and residual load-bearing capacity.

During the non-linear analysis, the software shows the graph of the trend of the convergence of the non-linear calculation as the percentage of applied load increases and for each type of applied load, as indicated in the boxes of the following figure:

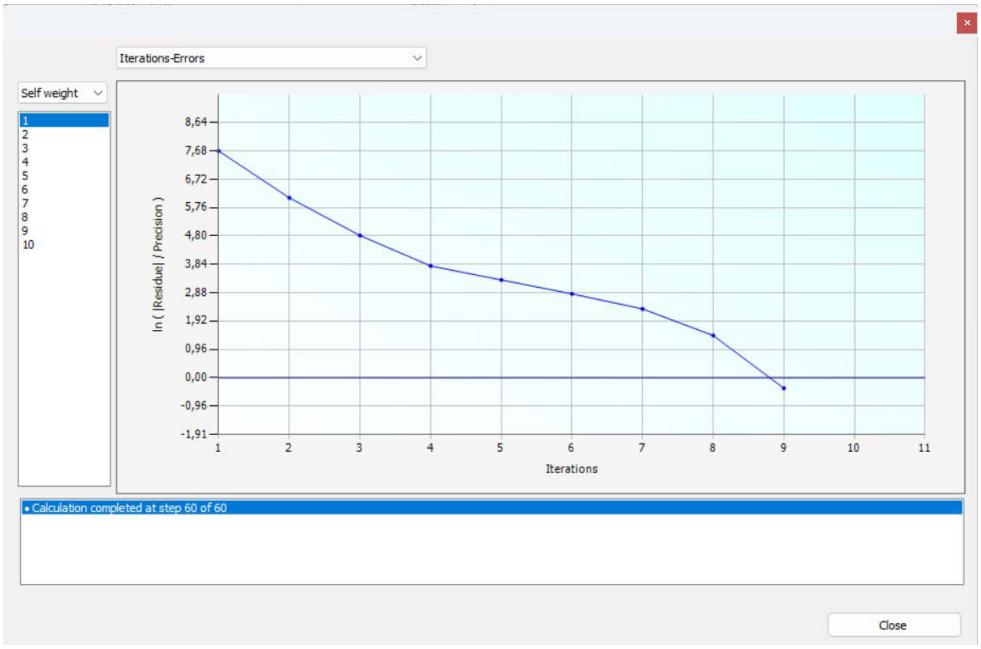


*Fig. 22 - Iterations-Errors graph for checking the trend of the convergence of the nonlinear calculation as the percentage of applied load increases*

The nonlinear static analysis stops when the equilibrium of the forces acting on the vault is not reached and the software provides the risk indicator ζV for vertical loads of a static nature (NTC2018 - §8.3) and the collapse multiplier, as shown in box 5 of the following figure:


*Fig. 23 - Capacity curve of the vault, or the graph that reports on the X-axis the displacement of a control node, which by default is the node that at the end of the calculation has a greater vertical displacement, and on the Y-axis the load applied to the vault in a progressive manner.*

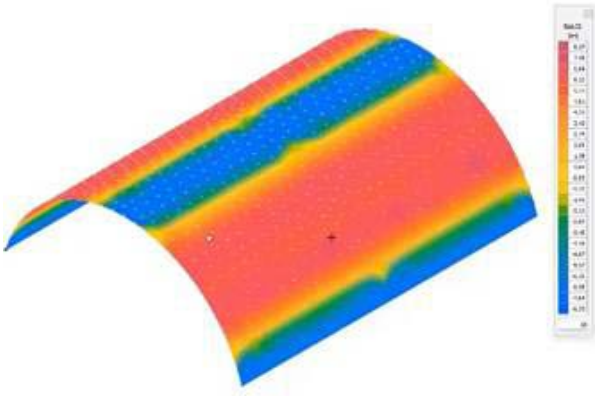

*Fig. 24 - Graphical display of the results of the nonlinear ULS analysis of the eccentricity between the load resultant and the mean plane of the vault at each step of the incremental analysis.*

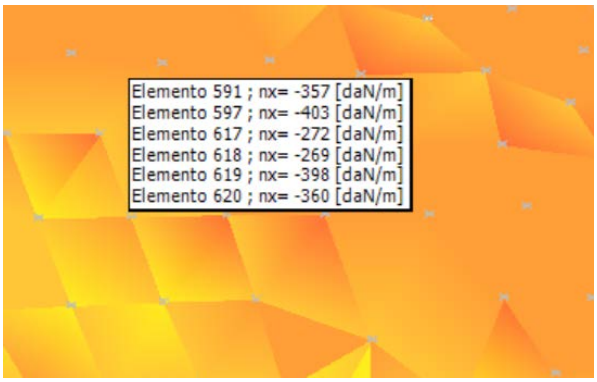


*Fig. 25 - Viewing stress results by moving the mouse over the 3D surface*

3Muri Vaults raises the level of precision in the design of complex structures and optimizes engineering practice.