Diagonalization strategies in search of structural optimization

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Abstract

Topology optimization has traditionally been used in continuous geometries, but due to the widespread presence of discrete structures it becomes necessary to present new methods. The following text is committed to achieve the topology optimization of diagonalized structures employing new tools at our disposal, with application to a singular structure, the Seville April Fair gateways. To facilitate this task we propose first generating these spatial meshes automatically by the parametric design software Grasshopper, so that enables the immediate generation of different diagonalization configurations for further evaluation by the analysis software SAP2000. Then, using the 3D physical simulator Kangaroo is sought, in a systematic way, optimized diagonalization proposals. The optimization process is to preserve the elements that satisfy the condition (final length - initial length) > initial length/X, which are those that present greater deformation, and therefore, those who suffer a significant axial force. This process has considered twelve progressive steps, with different values of X, making it possible to detect the most appropriate direction of diagonalization.
Keywords: Seville April Fair gateways, spatial framework, diagonalization, optimization, Grasshopper, Kangaroo.

1 Introduction

Seville Fair gateways are constituted as large space structures composed of tubular elements connected by clamps (fig. 1). The organization of these spatial structures is that of an orthogonal grid formed by prismatic modules diagonalized in one direction in every face, whose dimensions are 1.00 m in the OX direction -front elevation, variable dimension in the OY direction -transverse elevation- and 1.70 m in the OZ direction (fig. 2).

WIT Transactions on The Built Environment, Vol 137,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/HPSM140361

Figure 1: Spatial structure during the building process, 2010.

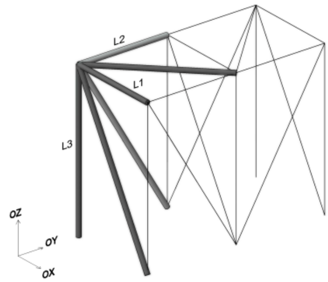

Figure 2: Prismatic Module, L1 = 1.00 m, L2 = Variable, L3 = 1.70 m.

Thus, a variable number of vertical planes hatched with horizontal and transverse planes are established. The following images show the construction of the Seville April Fair gateways corresponding to different years, through repetition in the front elevation of the prismatic modules that fit the contour defined by the given shape, and depth to achieve the desired thickness. The premises adopted for the configuration of this spatial structure provide a simple, cheap and fast answer for its construction every year.

2 Automatic generation of spatial framework

It is proposed initially the development of a parametric model to enable the immediate generation of different geometrical solutions making use of parametric design software Grasshopper v. March 07.2011. The parametric model to generate will be homogeneous and uniform, so that all prismatic modules will have identical dimensions, and the number of prismatic modules in the OY direction will be the same throughout the model, i.e., the spatial model will present constant thickness over the whole of its set.

Considering these premises, steps for the development of the parametric model are detailed below:

1. Definition of a parameterized flat mesh of points, contained in the OXZ plane.
2. Selection from among all the points of the flat grid generated above, of those included in the corresponding contour (fig. 3(a)).
3. Repetition in the OY direction, also parameterized, of the flat mesh of points adapted to the outer contour, to constitute the vertical planes that make up the geometric pattern in each case, obtaining thus finally a spatial mesh of points parameterized in the three global directions OX, OY and OZ.
4. Union of points in the three main orthogonal directions to generate the different vertical, horizontal and transverse frame-elements for the spatial configuration of prismatic modules. Moreover, in the case of frontal,

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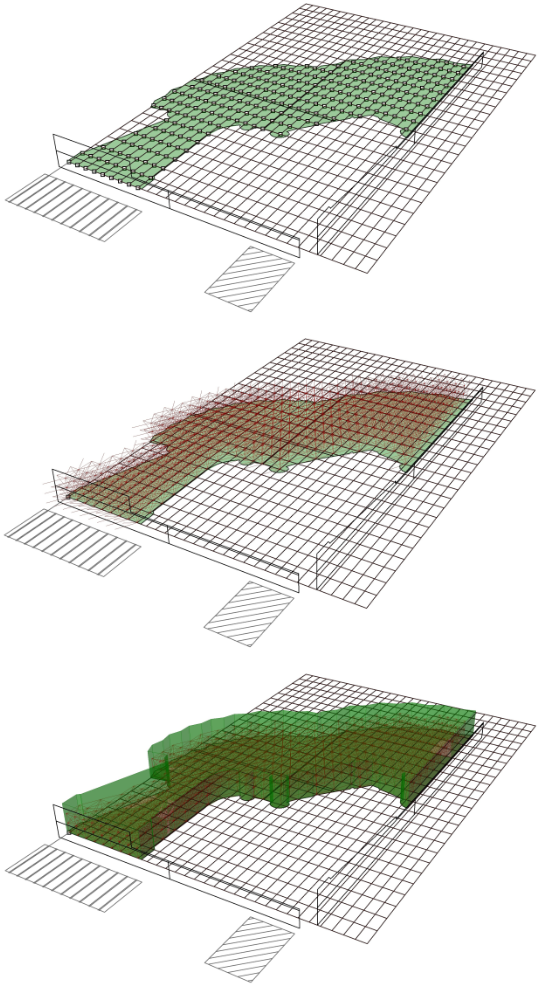
transverse and horizontal diagonal frame-elements, these are generated in the two possible directions of diagonalization, such that subsequently we will select in each case those ones that interest us (fig. 3(b)).

5. Once the spatial structure is thus formed, it is necessary to establish the solid within which it can be contained, generated from the extrusion of the front elevation (fig. 3(c)).



(a)

(b)

(c)

Figure 3: Steps during the development of the parametric model.

3 Diagonalization strategies in structural optimization search

Different types of structural optimization that can be considered depending on which design variables are used (Victoria Nicolás [1]). Of the four main types of variables that can be found, the material of the structure, the geometric properties of the section, the geometry and the topology of the structure, we will focus on the fourth parameter, i.e., the definition of number of elements (or cavities in the case of a continuous geometry) that make up the structure.

The objective of topology optimization is to find the best use of materials of a structure establishing for that objective criteria (global stiffness, natural frequency,...) and drawing a maximum or minimum subjected to given constraints, usually volume reduction. In this type of optimization the material distribution function serves as an optimization parameter (Yulin *et al.* [2]). Traditionally, this method has been used in continuous geometries so that, to date, almost all works regarding topology optimization have focused on shell and solid structures (Zhen *et al.* [3]).

Topology optimization is a very important tool in order to optimize continuous geometries but due to the extensive presence of discrete structures and limitations of this tool to address their optimization, it is necessary to approach new methods or modification of current ones to include the peculiarities of the mentioned structures (Alcalá *et al.* [4]).

In our discrete model in particular, the parameter on which we really want to act is to choose the diagonalization direction for each of the three principal directions (frontal, horizontal and transverse diagonalization), compared to the double diagonalization shown above. We intend to achieve structural topology optimization considering as objective function the reduction by 50% of the diagonal elements of the initial proposal with two-way diagonalization, and therefore, a very significant reduction of structural self-weight.

3.1 Proposals obtained by the 3D physical simulator Kangaroo

The following section is committed to use the 3D physical simulator Kangaroo for parametric Rhinoceros Grasshopper software to obtain in a systematic way new diagonalization proposals pursuing the same objective function: 50% reduction of the diagonal elements to provide over the initial two-way diagonalization proposal. The optimization process proposed is as follows:

Suppose a parametric model entered to Kangaroo and calculated its stable configuration according to certain loads implemented in the nodes of the structure and defined anchor points of the same. If any item is not subjected to large axial forces that element is probably not necessary so it could be removed. The way to determine if an item is subjected to large axial force is to check its deformation after simulation, comparing its final to its original length; thus, we can differentiate between elements lengthened and those who were shortened, representing them in different colors. If any element is slightly deformed and shows relatively low axial force with respect to other elements, that element could be eliminated thus achieving the topology optimization (Araya [5]).

To prove this hypothesis it is presented first a simple example corresponding to a planar truss under gravitational joint loads, verifying the hypothesis developed with the simulator "Kangaroo", comparing the results obtained in terms of deformations in the Kangaroo software with the results obtained on the same model in terms of axial forces in the SAP2000 software (fig. 4).

Three different tests are performed in Kangaroo, which are requested to retain those elements whose deformation is greater than 0.5%, 1.0% and 2.0% of the initial length of the element respectively, so that in each case are retained respectively 18, 13 and 7 elements of the 20 elements of the truss shown (fig. 5), and checking that the removed elements correspond to those with less axial force in the prior numerical analysis by SAP2000.

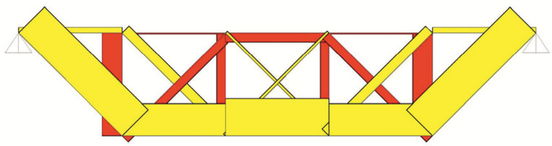


Figure 4: Planar truss in SAP2000 with axial forces after simulation.

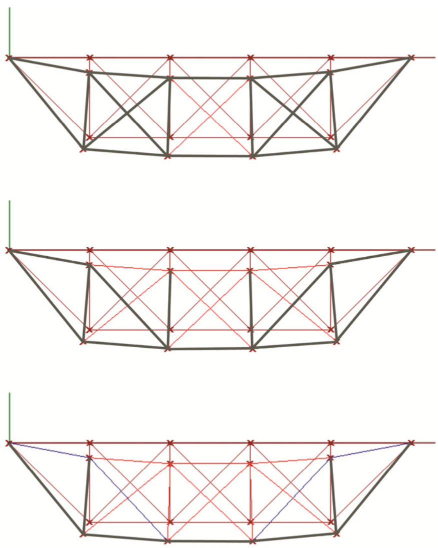


Figure 5: Planar truss in Kangaroo after simulation. (01): Final length – Initial length > 0.5% of Initial length. (02): Final length – Initial length > 1.0% of Initial length. (03): Final length – Initial length > 2.0% of Initial length.

After verifying the effectiveness of the optimization process in Kangaroo on a simple example, it will be evaluated on parametric models corresponding to the Seville Fair gateways generated previously. The topological optimization process will be exclusively applied to the front diagonal elements, since of the three existing diagonalization directions this is the most difficult to deduce intuitively. In this way, we will be able to reduce by 50% the number of frontal diagonal elements and the number of staples of connection between these, and thus, the structure self-weight. The proposed optimization process is as follows (fig. 6):

Only the elements that satisfy the condition "(Final length – Initial length) > (Initial length/X)" will be retained, that will be those who present greater deformation, and therefore, those who suffer a significant axial force. In this process twelve steps have been considered, in which progressively those diagonal frontal elements having less deformation are eliminated by taking X = 300, 200, 150, 100, 90, 80, 70, 60, 50, 40, 30, 20.

The model obtained upon consideration of all steps analyzed is shown, in which an optimization of 50% is achieved on the initial proposal, also representing the thickness of tubular elements showing their effort level (fig. 7).

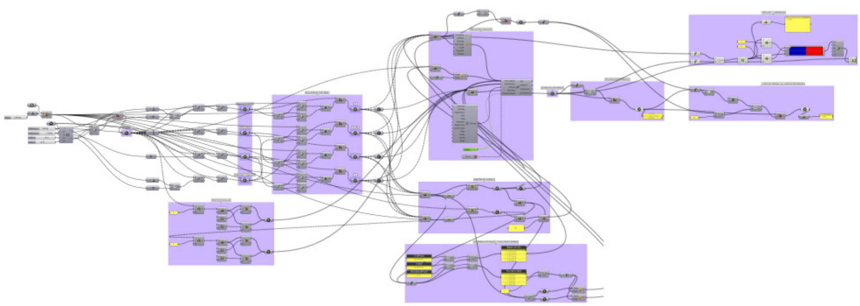


Figure 6: Optimization process in Kangaroo.

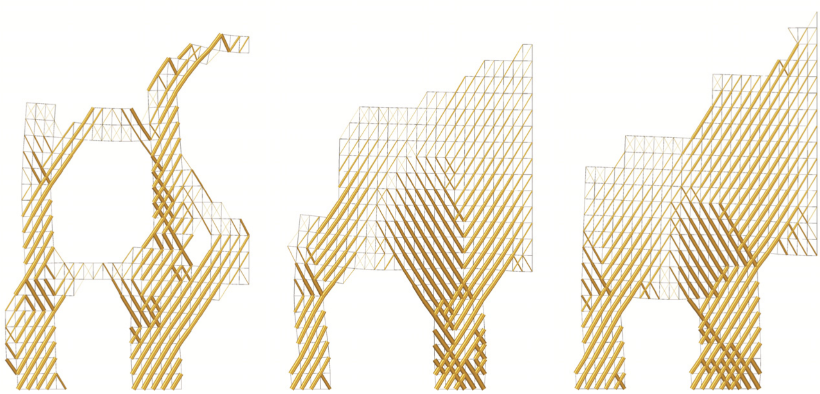
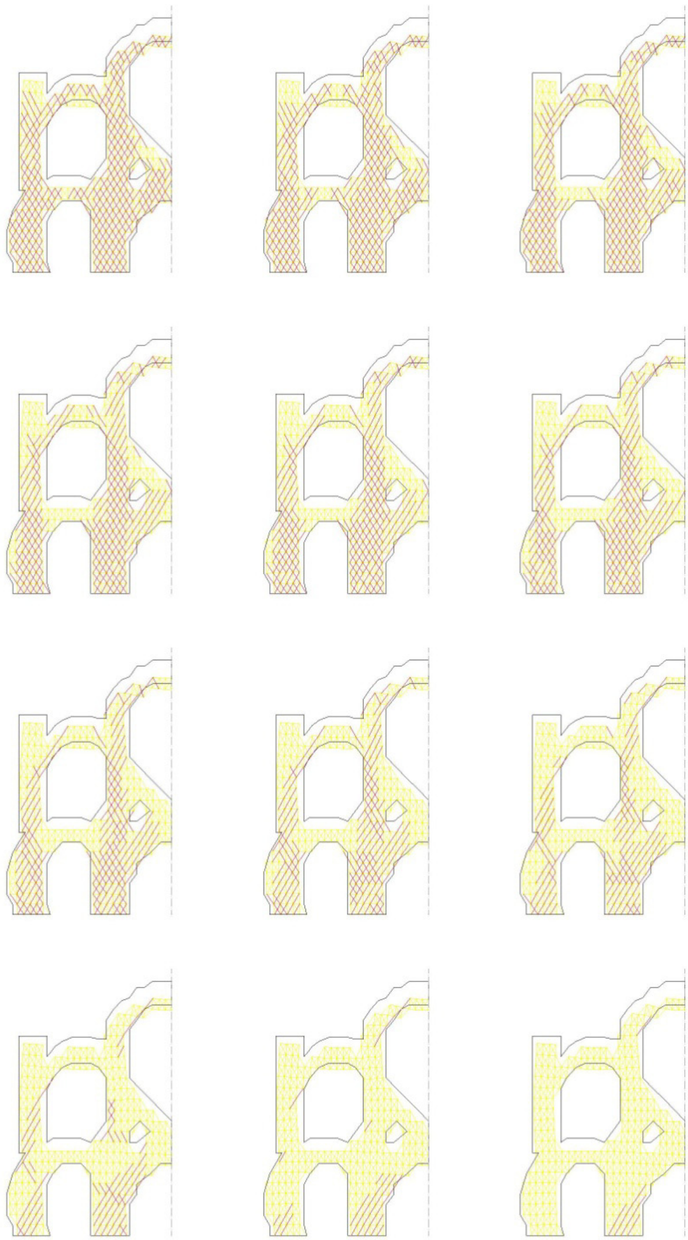


Figure 7: Final front diagonalization models with representation of axial force level under gravity loads.

Finally, the results obtained show on the initial two-way diagonalization proposal the progressive elimination of diagonal elements according to the steps mentioned above, indicating the number of front diagonal elements remaining in each step for three gateways corresponding to three different years, 2010, 2011 and 2012 (table 1 and fig. 8).

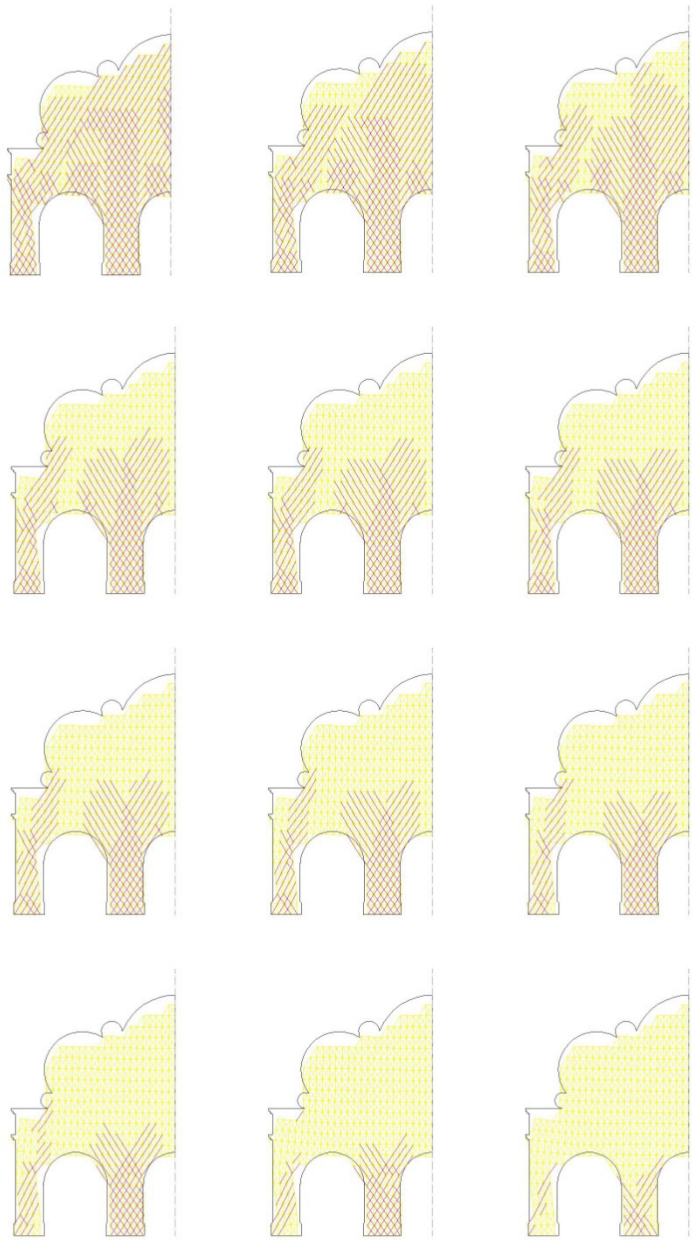
Table 1: Percentage value of front diagonal elements remaining in each step.

	Fair gateway 2010	Fair gateway 2011	Fair gateway 2012
Total	2,338 100%	3,185 100%	3,530 100%
X = 300	1,930 82.55%	2,320 72.84%	2,620 74.22%
X = 200	1,765 75.49%	1,975 62.01%	2,365 67.00%
X = 150	1,635 69.93%	1,705 53.53%	2,170 61.47%
X = 100	1,390 59.45%	1,295 40.66%	1,765 50.00%
X = 90	1,325 56.67%	1,200 37.68%	1,655 46.88%
X = 80	1,215 51.97%	1,125 35.32%	1,510 42.78%
X = 70	1,065 45.55%	1,045 32.81%	1,335 37.82%
X = 60	940 40.21%	940 29.51%	1,100 31.16%
X = 50	715 30.58%	835 26.22%	925 26.20%
X = 40	445 19.03%	695 21.82%	710 20.11%
X = 30	210 8.98%	520 16.33%	465 13.17%
X = 20	90 3.85%	220 6.91%	130 3.68%



(a)

Figure 8: Iterative optimization process applied to the front diagonal elements on the Fair gateway (a) 2010; (b) 2011; (c) 2012.



(b)

Figure 8: Continued.

(c)

Figure 8: Continued.

WIT Transactions on The Built Environment, Vol 137, © 2014 WIT Press
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4 Conclusions

It is possible to compare the diagonalization proposals obtained with Kangaroo with those that correspond to solutions implemented actually coming from the experience of the designer (fig. 9). It is observed that there is an extensive correlation between both proposals, which confirms the validity of the proposed method.

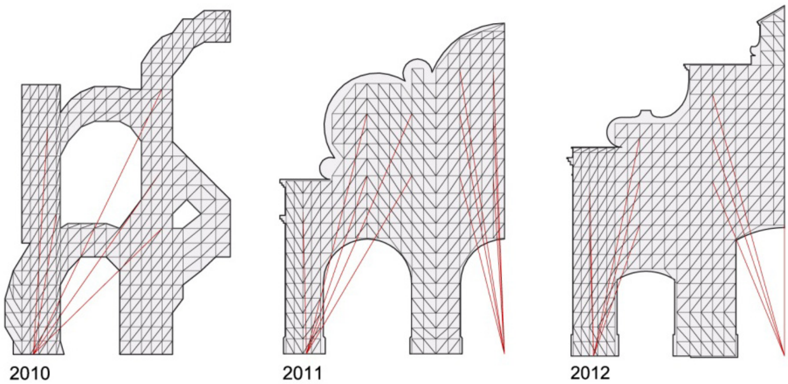

Figure 9: Execution models corresponding to the Seville Fair gateways.

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