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Design and Experimental Testing of the Bundled Glass Column

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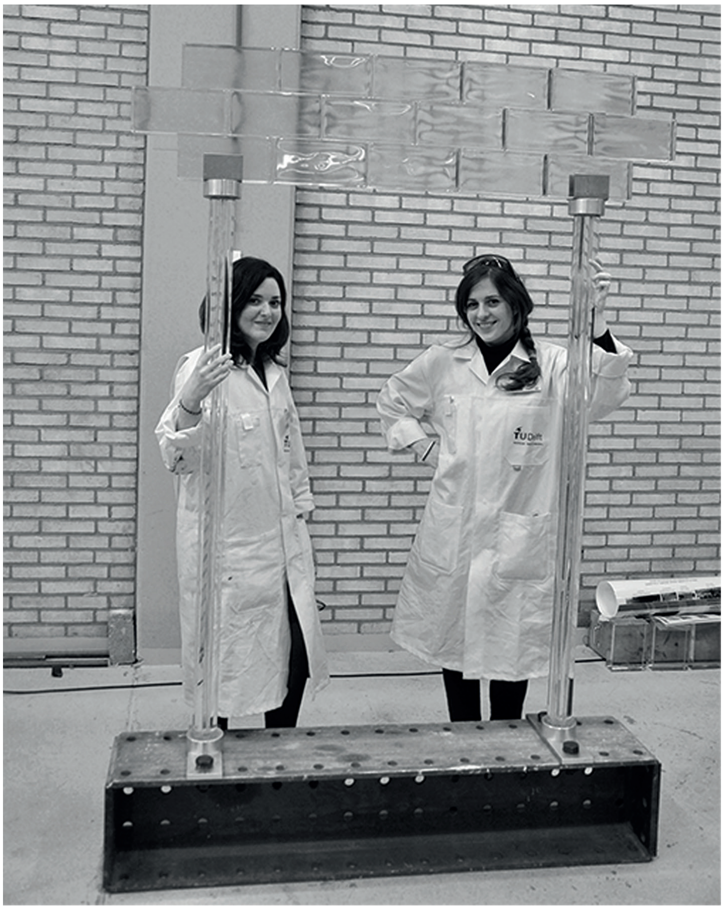
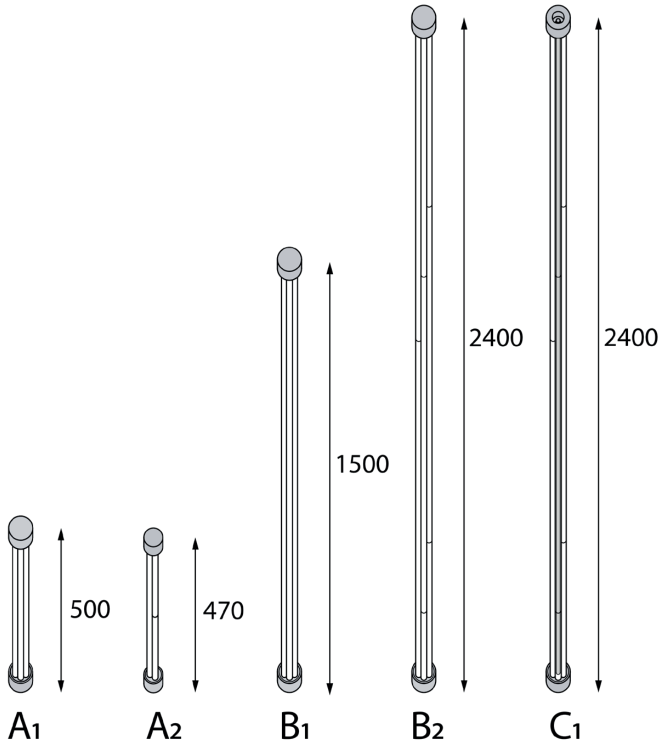
Abstract (The complete contribution will be published in the Glass Structures & Engineering journal)

In this paper, a transparent bundled glass column is presented as a promising solution for diaphanous compressive members.
Owing to the high compressive strength of glass and its most characteristic attribute, transparency, a glass column is capable of transferring compressive loads while allowing for space and light continuity. Several different all glass columns have been explored in the past, nevertheless, they are seldom applied in construction. Reasons include complications in fabrication, absence of statistical strength data but above all lack of a built-in safety system due to the inherent brittleness of glass.
The goal of this research is to develop a glass bundled column in a scale relevant to buildings that can safely carry loads, have a high visual result and be easily manufactured. Towards this aim, the paper presents an overview of the research conducted by the authors from the design concept to the manufacturing, engineering and experimental testing of full-scale prototypes.
The concept of the bundled column is in itself simple: Multiple glass bars are bonded together by a colourless adhesive, forming a composite yet unified cross-section. To investigate the feasibility of the bundled column for real applications, first a production method is developed for manufacturing specimens in a scale relevant to buildings with guaranteed consistency in their structural and visual performance. Initially, different glass rod configurations, adhesives and bonding techniques were explored in search of a combination that would (a) ensure the desired coupling degree of the individual rods, (b) achieve minimum visual flaws and (c) result to an easy and standardized manufacturing method. The final column consists of a central, star-shaped, hollow CONTURAX® profile with 17(±2.00) mm inner and 30(±2.00) mm external diameter adhesively bonded by a clear, UV-curing adhesive to 6 DURAN® rods of Ø 22(±0.45) mm diameter. All used rods are standardized, extruded borosilicate profiles, 1500 mm in length by SCHOTT.
The degree of coupling between the individual rods is investigated through experimental testing of a series of prototypes of 500 mm length [A_1 series]. The consistent, high failure stress of approximately 500 MPa suggests that the high shear stiffness of the selected adhesive enables the bundle to behave as a single monolithic unit under the anticipated compressive forces.
The employed extruded profiles are standardized up to 1500 mm length. Thus, longer prototypes are made by adapting the splice lamination principle: To prevent the introduction of weaker zones, each column is segmented in such a way that the connection points spiral up along its height. In order to evaluate the degree of influence of the splice lamination joint, alternative connection types (a small gap, an adhesive connection and an insert of a 2mm thick aluminium disc) are experimentally tested in a series of 470 mm long [A_2] specimens. The results point out that specimens with aluminium discs in the split joints performed the closest to the monolithic variant.
Next, three series of prototypes [B_1, B_2 and C_1] up to 2.4 m in height are made and tested in compression to investigate the failure behaviour and structural performance of the designed column. Custom-made metal caps with an inlayed lead layer are mounted to each column's ends to prevent the direct contact of glass with the steel surface of the machine. With the aim of securing a more gradual and thus safer failure, a post-tensioned steel tendon is introduced to one of the 2.4 m long series [C_1] and experimentally evaluated.
The results demonstrate that the chosen adhesive and rod configuration enable the designed column to perform monolithically under loading and fail by buckling in values close to the theoretical buckling force of the corresponding solid bundle. The spliced joints and eccentricities occurring during fabrication seem to have only a minor influence on the resulting stresses.
Nevertheless, all specimens without post-tensioning failed in a complete way without maintaining any post-breakage load-carrying capacity; thus not providing a safe failure behaviour.
In contrast, the post-tensioned specimens present a more consistent and visible failure and a narrow load spread, suggesting that post-tensioning allows for a more predictable failure, which in turn provides increased structural reliability. After failure, the post-tensioned specimens preserved a limited load-bearing capacity, attributed mainly to the tendon. In this direction, the steel tendon can in the future be engineered to provide an alternative, built in load path that can reduce the consequences of failure. Yet, the specimens of this series demonstrated a lower load-bearing capacity, which is ascribed to the insufficient cooperation between the tendon and the glass, due to inevitable manufacturing tolerances. By optimizing the contact between tendon, sheathing and the glass bundle, the lateral movement of the glass bundle leading to eccentricity can be constrained, resulting in higher failure loads.
Overall, the results indicate that the bundled glass column can be an elegant solution of sufficient compressive strength in the search of a transparent, load-bearing component.
With the aim of applying the bundled glass column in future structures, further work will focus on the development of the top and bottom connections as well as on improving the post-tensioning mechanism towards a safer and stronger all-glass column.
The presented glass column design is first applied in the truss elements of a temporary pedestrian 14 m long bridge at the TU Delft campus.





Left: Realized 1.5m long prototypes of the bundled column by the authors
Right: Illustration of all specimen series tested in compression (length dimensions in mm)

Rod configuration of the final bundled column design.