Short report on the research project:

Development of planar prefabricated brick shells for the production of wide-span shell structures

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The responsibility for the content of the research report lies with the authors.

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1. Initial situation

Shell structures have a high potential for the building industry from the point of view of building culture and load-bearing construction as well as aesthetics. Although they have numerous advantages over other constructions, they are rarely used in today's architecture due to high costs. The buildings of Felix Candela, Eladio Dieste and Heinz Isler are impressive examples of the efficiency of this construction method.

2. Subject of the research project

The relevance of the research topic is clearly demonstrated by the relative absence of shell structures in the number of new construction projects. This is due to the high use of resources for personnel, formwork and substructures, such as falsework. To counteract this problem, it is necessary to reduce the proportion of personnel and formwork, simplify falsework and optimise the planning, production and construction processes.

Our research approach envisages a methodology for the economical production of multiple curved brick shells using simple, planar components. The aim is to make complex structures such as shell structures more competitive by increasing the degree of prefabrication, thus increasing the diversity of this type of structures (see Figures 1 to 4). This problem can be counteracted by transferring a large part of the work from the construction site to prefabrication.

Figure 1: External view - Depositas Montevideo, A1

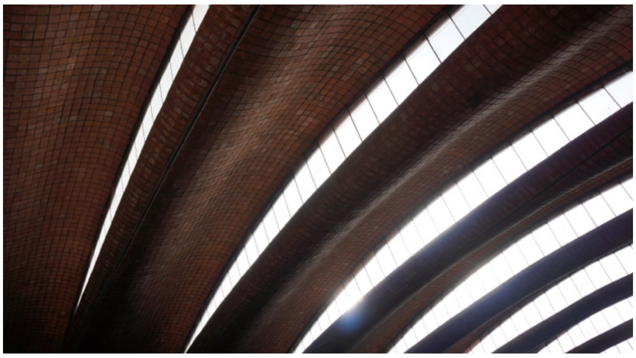


Figure 2: Roof structure - Depositas Montevideo, A2

Figure 3: Diestes brick shells, A2

Figure 4: Diestes brick shells, A2

In a form finding process an exemplary shell geometry with dimensions of 15 x 5 m was developed, which is subdivided into planar elements in a subsequent optimization process.

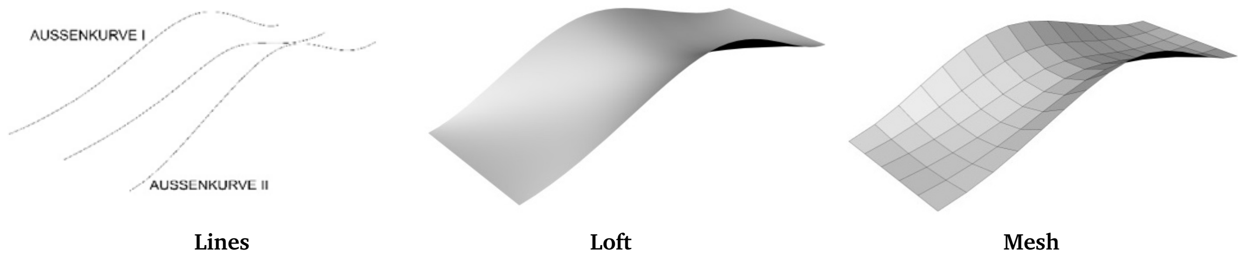


Figure 5: Form generation, A2

In the optimization process, various boundary conditions are defined on the basis of module geometry requirements, which can be set as equilibrium and weighted differently in an iterative process. In the next step the bricks are being distributed onto planar finished parts using a parametric model (see Figure 6).

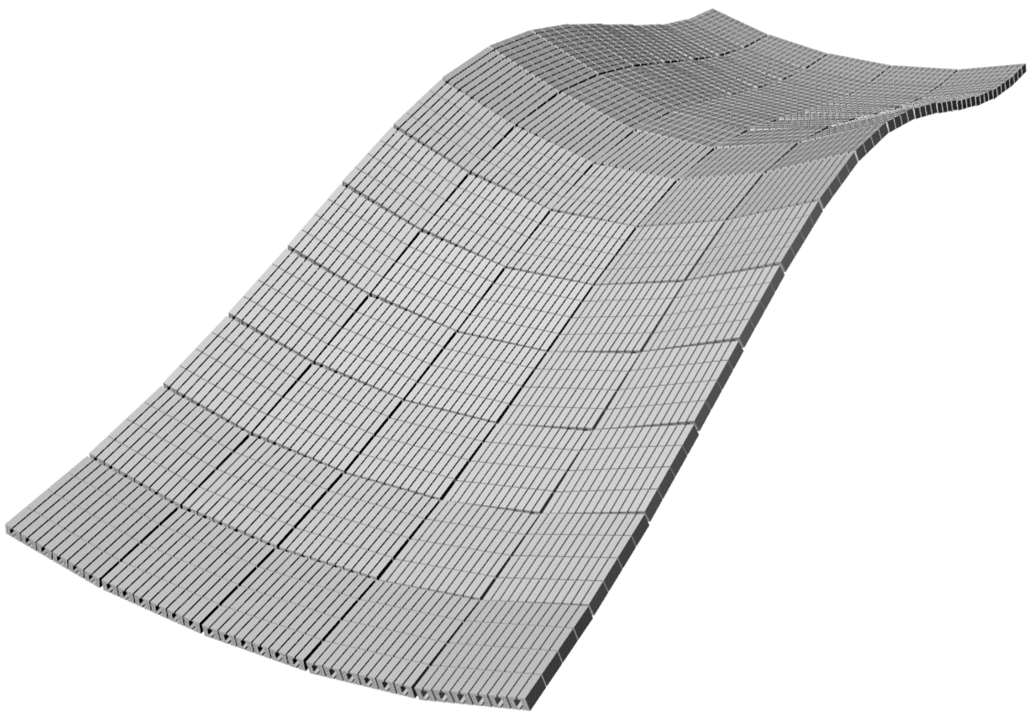


Figure 6: Parametric model of precast brick elements and bricks, A2

The individual prefabricated parts of the shell are output as 2D processing, which are then examined in the further constructional steps. In the process, connections are developed which ensure the transfer of membrane forces from prefabricated part to prefabricated part. Based on the results from the structural part of the research project, different standard bricks are then selected and optimized. Within 4 test series different bricks will be developed, which will be optimized with regard to the joints and for the inclusion of reinforcement.

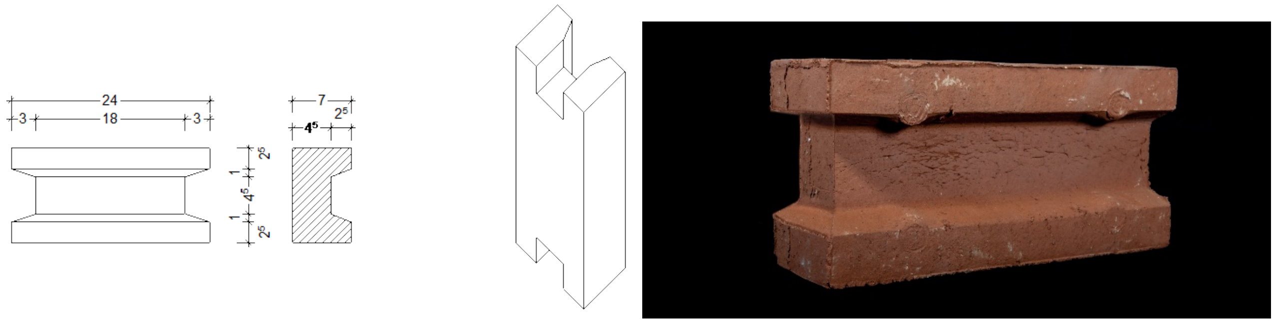


Figure 7: Test series 3 - Recesses in the end areas of the brick, A2

This is followed by a feasibility study at the precast plant. The individual precast elements are assembled from the optimised bricks within the 4 test series to form segments. This allows the connections and the construction to the different bricks as well as the joint mechanisms to be checked and analysed.

Figure 8: Rest series 2:
Falsework with individual ends, A2

Figure 9: Test series 2:
Falsework - support for precast element, A2

The feedback of the results from the previous steps is then used to develop the final bricks and the joint mechanism. The knowledge gained from the static calculations and the optimisation of the bricks, prefabricated brick parts and the falsework is fed back into the digital model and optimized (see Figure 10).

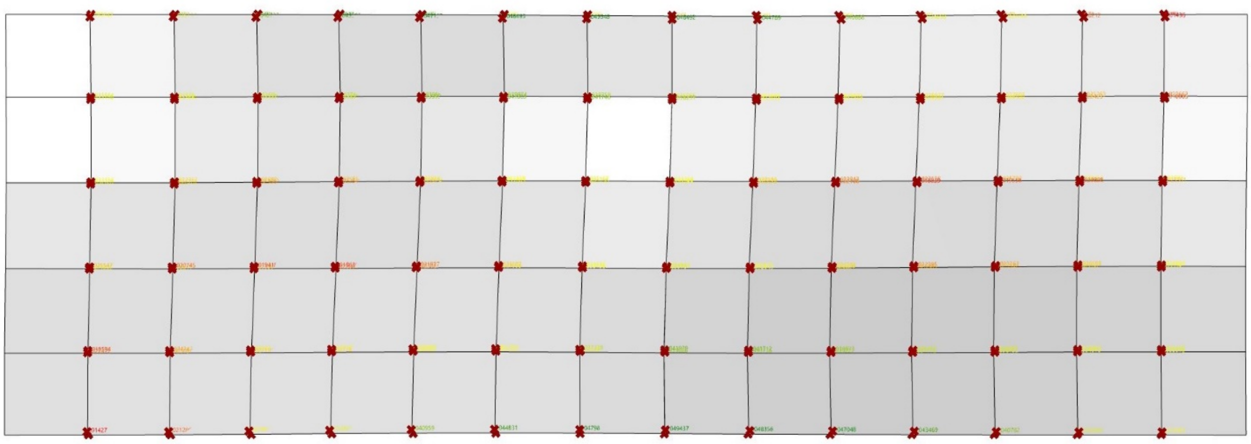


Figure 10: Exemplary part of the optimization: Color illustration of the distances between the finished parts, A2

At the end of the research project, a 5 x 15 m shell will be constructed as an experimental structure. First of all, a falsework - developed from the digital model and transferred to production (CAM) - is erected (see Figure 11).

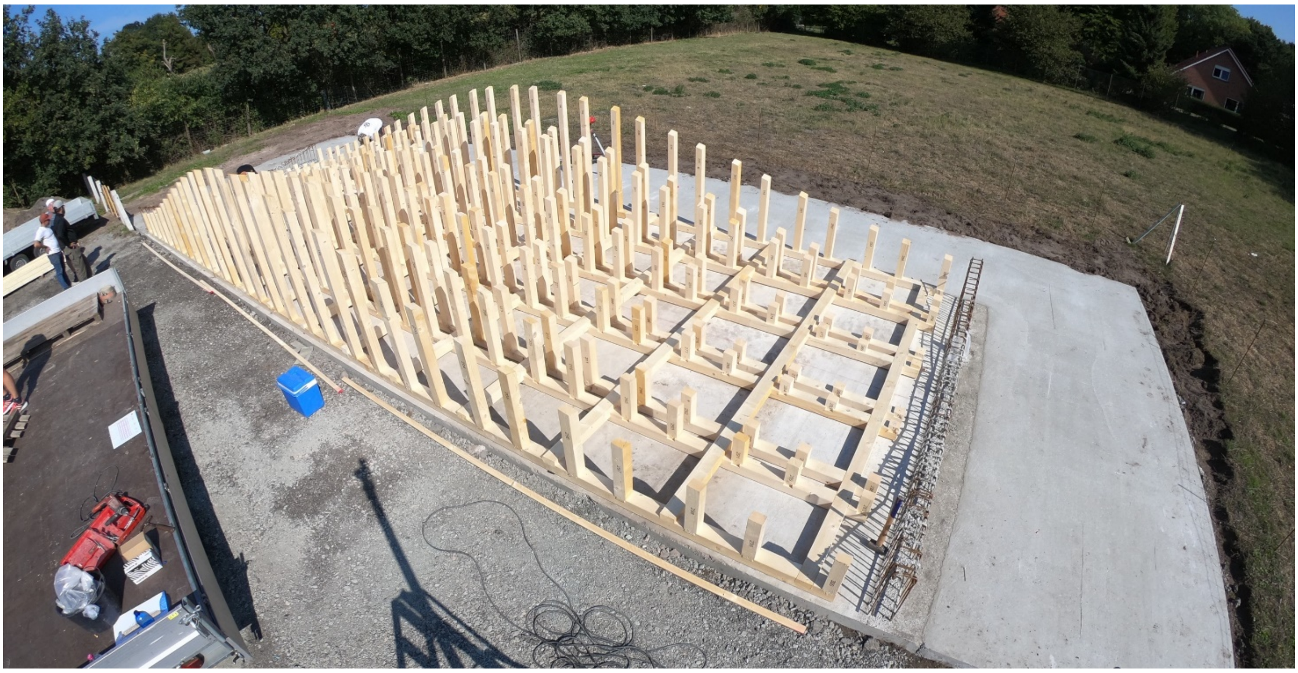
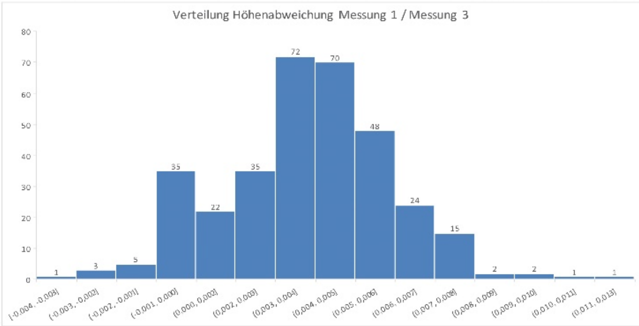


Figure 11: Assembled falsework without transverse bracing, A2

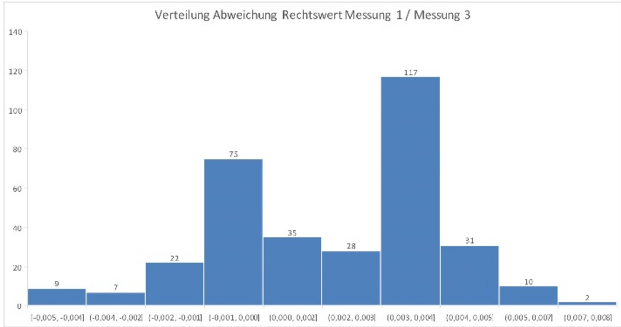
Subsequently, the shell is examined by surveying iteratively in order to verify the constructive assumptions made to determine deformations.

Figure 12: Corner and border targets, A2

Figure 13: Target mark and prism, A2



Altitude - Zero measurement / load, A2



High value - Zero measurement / load relieved, A2

Figure 14: Exemplary diagram sections, A2

The anticipated deformations were, for the most part, declining after relief, whereby a portion of the deformations did not return to the zero state. At a length of approx. 15 m, height deviations under load of a maximum of 19 mm occurred to a small extent, with a large part in the range of 9-11 mm (see Figure 14).

3. Conclusion

In summary, the results confirm the assumptions and the brick shells can be represented by planar elements. The fact that the assumptions generated and verified in the digital model could be implemented 1:1 in reality, despite high tolerances in building construction, shows how well digital design and manufacturing techniques can be supplemented with conventional construction methods.

In conclusion, it can also be said that the research project exceeded our expectations.

Figure 15: Side perspective with the curvature, A3

4. Key data

Short Title::	Shell Structures made of Prefabricated Bricks
Total Costs:	375,275.47 €
State Subsidy:	235,070.84 €
Project Duration:	32 months, 10.10.2016 to 30.06.2019

5. Figures

A1 - **Anderson, Stanford** (Hrsg.): Eladio Dieste, Innovation in Structural Art, Princeton Architectural Press New York, 2004.

A2 – Author

A3 - virtua ethic Düsseldorf