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Design, fabrication and assembly of a cardboard pavilion based on an isogonal moulding surface

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Abstract

This paper presents the design, fabrication and assembly of a cardboard gridshell pavilion constructed during a two-day workshop at Chalmers University of Technology. The project investigates how geometric constraints embedded within a computational design workflow can reduce part diversity and enable the construction of spatial structures using simple fabrication methods and limited tooling. The pavilion geometry was derived from an isogonal moulding surface, a subset of discrete Monge surfaces characterised by congruent torsion-free nodes and planar quadrilateral elements. These geometric properties were used to rationalise the structure towards a limited set of member lengths and node configurations while maintaining geometric continuity across regions of both positive and negative Gaussian curvature. A parametric workflow was developed to discretise and rationalise the surface geometry and to generate instructions for the manual fabrication and assembly. The structure was fabricated from flat cardboard strips of constant width cut from standard corrugated sheets, with connection details integrated directly into the members through controlled end-creasing, eliminating the need for separate connectors. The pavilion was constructed using basic hand tools through a modular assembly process carried out by groups of students. Despite its doubly curved non-developable geometry, the pavilion required only 20 unique member lengths and 6 unique fold angles across 684 members and 357 nodes. The project demonstrates how restricting geometric freedom at the computational design stage can support low-tech construction workflows for doubly curved spatial structures.

Keywords: gridshell structures, geometric rationalisation, isogonal moulding surfaces, conical quadrilateral meshes, low-tech fabrication, cardboard construction.)

1. Introduction

Doubly curved spatial structures pose inherent challenges in reconciling geometric complexity with practical construction constraints. Although contemporary computational design tools enable increasingly complex free-form geometries, their physical implementation typically depends on high fabrication precision, bespoke components, and specialised manufacturing processes. Geometric rationalisation strategies respond to these fabrication and construction challenges by embedding fabrication-aware constraints directly into the design process, simplifying the geometry while preserving the initial design intent [1]. In this context, geometric constraints are treated not only as limitations to be resolved but also as a design catalyst informing architectural expression, fabrication logic, and assembly strategy.

The project presented in this paper was developed as part of the course *Digital Tools–Parametric Design* for second-year Architecture and Engineering students at Chalmers University of Technology. The course includes a design-build workshop centred around computational geometry and digital

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fabrication. In 2024, the workshop focused on the construction of a doubly curved cardboard gridshell using elementary fabrication methods and limited tooling. The structure was required to be fabricated and assembled within a two-day workshop by students with limited prior construction experience. Given the reliance on elementary tools and the lack of precision digital fabrication methods, the design strategy focused on minimising part variation, simplifying connection details, and reducing sensitivity to fabrication tolerances. Moreover, the project was initially conceived around the reuse of post-consumer cardboard packaging sourced through discussions with local restaurants and recycling actors. Although logistical constraints ultimately required the use of commercially sourced cardboard sheets, the anticipated variability in sheet dimensions and material quality informed the geometric rationalisation and fabrication strategy.

Several documented cardboard shell and pavilion projects employ highly differentiated component systems and numerous connection conditions, realised through both precision-cut fabrication workflows [2, 3] and comparatively simple manual production methods [4, 5]. In contrast, the present work sought to minimise part variation and simplify assembly through geometric rationalisation of both the surface discretisation and the connection logic. The pavilion geometry was based on an isogonal moulding surface as described by Mesnil et al. [6]. This family of surfaces exhibits geometric properties that reduce variation in member lengths and connection angles. The completed pavilion is shown in Figure 1.

Figure 1: Completed cardboard gridshell constructed during the two-day workshop at Chalmers University of Technology.

2. Design methodology

The pavilion was developed as an indoor temporary structure intended to serve as a gathering space during an end-of-term event. Corrugated cardboard was selected as the primary material due to its low environmental impact, recyclability, and potential for sourcing from local recycling streams. While its mechanical properties vary depending on sheet type and sourcing, the material is generally characterised by limited bending stiffness and sensitivity to local buckling, which introduce design-relevant constraints.

More specifically, the design was required to satisfy three primary fabrication constraints: (i) a limited set of discrete member lengths to simplify manual cutting and reduce assembly complexity, (ii) a limited set of connection configurations to simplify manual fabrication and assembly, and (iii) torsion-free geometric conditions to avoid uncontrolled bending and twisting of the cardboard, which could otherwise lead to local failure and unintended folding.

The geometric definition of the pavilion was based on an isogonal moulding surface, a discrete surface class characterised by a conical and planar quadrilateral topology [6]. It is constructed from two guiding curves, a *generatrix* and a *directrix*, positioned in orthogonal planes, as illustrated in Figure 2. The surface was generated within a parametric Grasshopper 3D workflow, which controlled the discretisation of the guiding curves and automated the generation of fabrication data, including member lengths, connection definitions, cutting lists, and member labels.

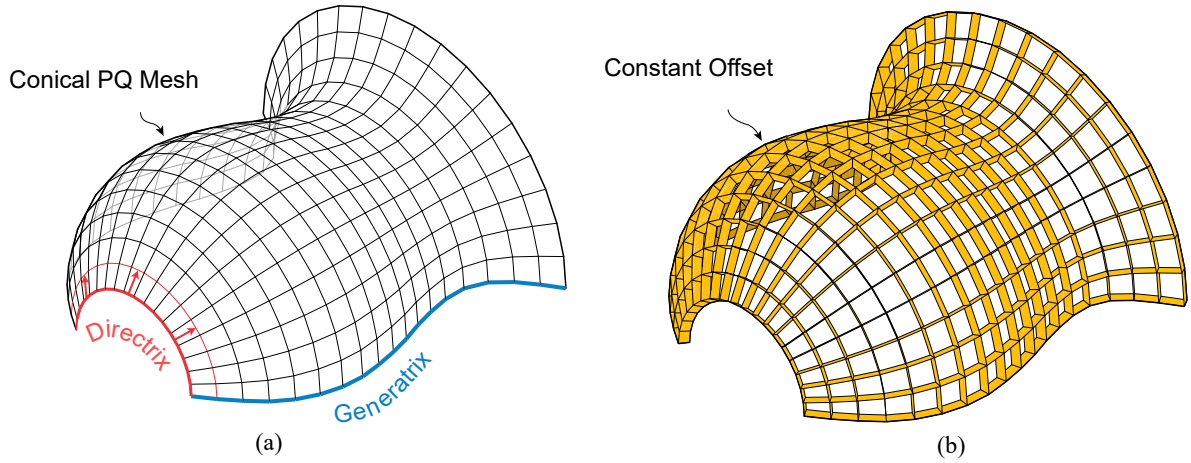

Figure 2: Generation of the grid shell geometry. (a) isogonal moulding surface generated by translating a generatrix along a directrix, (b) the members are found by applying a constant offset.

A free-form spline curve was used as the initial geometric reference for the generatrix, as illustrated in Figure 3. The procedure aimed to convert this curve into a discretised polyline with controlled segment lengths and a limited number of unique turning angles, i.e., the angles between consecutive segments. The curve was first discretised into 18 segments and scaled to match the target pavilion dimensions. The turning angle at each internal vertex was then evaluated. These angles were reduced to five representative values by grouping similar angles and rounding each group to the nearest integer degree. Finally, the curve was reconstructed as a polyline with uniform segment lengths using this constrained set of turning angles.

The directrix was defined as an isogonal discretisation of a semicircle, resulting in uniform turning angles and uniform segment lengths. This choice was motivated by architectural considerations, as the resulting radial symmetry was preferred for the overall spatial composition of the pavilion. Although a semicircle was selected in this case, arbitrary curves satisfying the isogonal condition can equally serve as directrices, enabling a wider range of spatial configurations within the same geometric framework. The construction procedure for such curves is described by Mesnil et al. [6]. The directrix, like the generatrix, was discretised into 18 segments.

Once the generatrix and directrix were defined, the isogonal moulding surface was generated through a discrete marching procedure following the construction principles outlined by Mesnil et al. [6]. Segments of the directrix were translated along the generatrix, and their endpoints were projected onto bisector-planes, defining successive surface nodes. The resulting mesh had a planar conical quadrilateral structure characterised by identical generatrix curves and a radially scaled set of directrix curves.

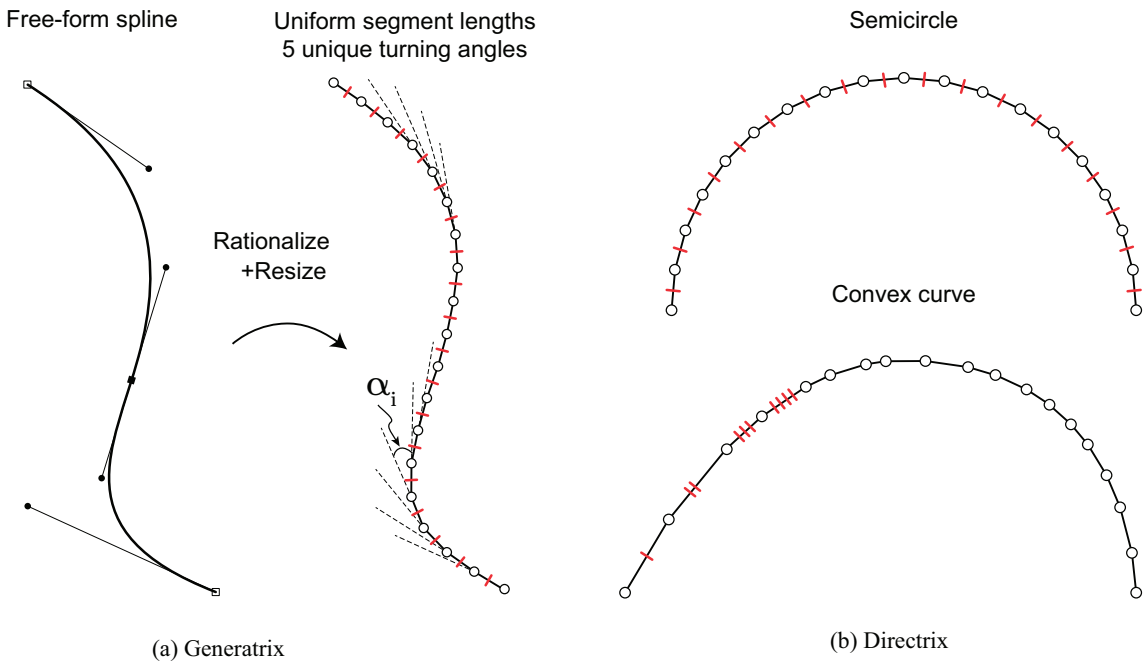

Figure 3: Construction of the guiding curves. (a) Rationalisation of the generatrix from a free-form spline into a polyline with uniform segment lengths and a limited set of turning angles α_i. (b) Isogonal discretisations of two admissible directrices: a semicircle and an arbitrary convex curve.

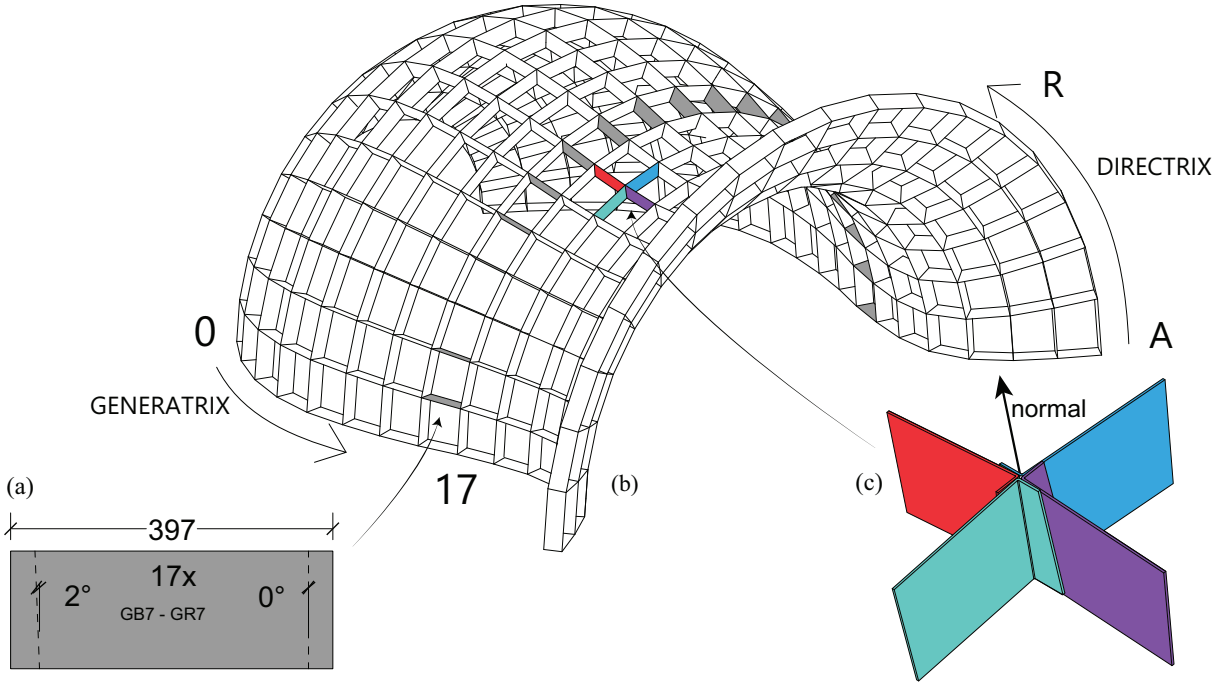

Figure 4: Fabrication information generated from the parametric model. (a) Example member drawing with cutting length, crease angles, label, and quantity. (b) Global member labelling scheme based on generatrix and directrix indices. (c) Node assembly illustrating the integrated folding connection detail between intersecting members.

Following the generation of the surface mesh, a constant offset of 145 mm was applied to visualise the structural members between adjacent nodes along the generatrix and directrix directions. Each member was then automatically labelled within the parametric workflow, with generatrix segments indexed from 0–17 and directrix segments labelled A–R, enabling unambiguous identification of individual members. The script also generated the geometry of bracing members required for global stability. Finally, fabrication drawings were produced for all unique elements together with their corresponding quantities. The members were extended by 30 mm at both ends to accommodate the integrated folding connection detail (see Figure 4). The required crease angle and the final cutting length were specified on the drawings.

The pavilion was designed to be self-supporting under its own weight of approximately 14 kg (≈137 N). A simplified post-fabrication check was carried out to estimate the buckling capacity of the most heavily loaded member. The member was idealised as a pinned–pinned column with length $L = 400$ mm, assumed to carry approximately 0.4 kg (≈3.9 N) in axial compression. For simplicity, the corrugated cardboard was modelled as a solid rectangular section, giving a weak-axis second moment of area $I = bt^3/12 = 326\,\text{mm}^4$. The material was assumed to behave as an isotropic elastic material with an effective Young's modulus of $E = 1$ GPa, which is representative of values reported for homogenised corrugated board in the machine direction [7]. The Euler critical buckling load was therefore estimated as $P_{\text{cr}} \approx 20$ N which is about five times greater than the estimated compressive force in the critical member.

3. Fabrication and assembly

The pavilion was fabricated from 3 mm single-wall corrugated cardboard sheets measuring 600×800 mm. Each sheet was first cut length-wise into four strips of width 145 mm using a circular saw, producing the base stock for the structural members. In total, 70 sheets were used for the primary structure together with an additional four sheets for bracing elements. The strips were subsequently cut to the lengths specified on the fabrication drawings. All primary cutting operations were completed prior to the workshop and required less than two hours using a single circular saw.

Following cutting, each element was inserted into a wooden creasing rig to produce the fold angle, as shown in Figure 5. Six rigs were manufactured corresponding to crease angles of 0°, 2°, 3°, 5°, 6°, and 11°. The crease was formed by manually grooving the cardboard using a wooden butter knife along a guide positioned 30 mm from the edge of the member. This ensured a consistent fold location and crease angle across all elements. Each member was subsequently labelled according to the indexing system, while centre lines, fold angles, and normal direction were annotated to support assembly alignment. Fabrication and preparation of all members required approximately two hours and was carried out by a group of around 15 students.

Assembly was carried out by six teams of three students each. The structure was subdivided into 36 assembly zones, as shown in Figure 6, with six divisions in each principal direction. Construction proceeded incrementally through a sequence of arch-like strips spanning the directrix direction, each composed of six connected zones. Individual zones were first assembled independently and then joined to form larger arch segments. These arches were subsequently connected to previously completed parts of the structure until the full shell geometry was established as shown in Figure 7 and 8.

Members were connected at the nodes using the integrated folding connection detail and secured with SeCo B 16 mm staples applied with Senior B16 stapling pliers. Each connection was fastened with two to four staples. During assembly, double-sided tape was temporarily used to position and hold members prior to stapling, allowing continuous assembly without interrupting the workflow. Once the first arch segment had been completed, bracing members were introduced in its end bay to stabilise the structure and prevent in-plane mechanism behaviour. The bracing members were fabricated from the same corrugated cardboard material but with a reduced width of 80 mm. These were assembled using the same folded connection logic as the primary members and arranged as planar cross-bracing elements.

As assembly progressed, completed arch segments were incrementally positioned and connected using a mobile scaffolding platform to access elevated regions of the structure. Additional bracing was introduced in the final end bay and within the central region of the pavilion to increase global stiffness, although the structure was observed to achieve substantial rigidity already through end bracing alone. The full assembly process required approximately one and a half days to complete. The construction process was documented by Adiels in a time-lapse video available online [8].

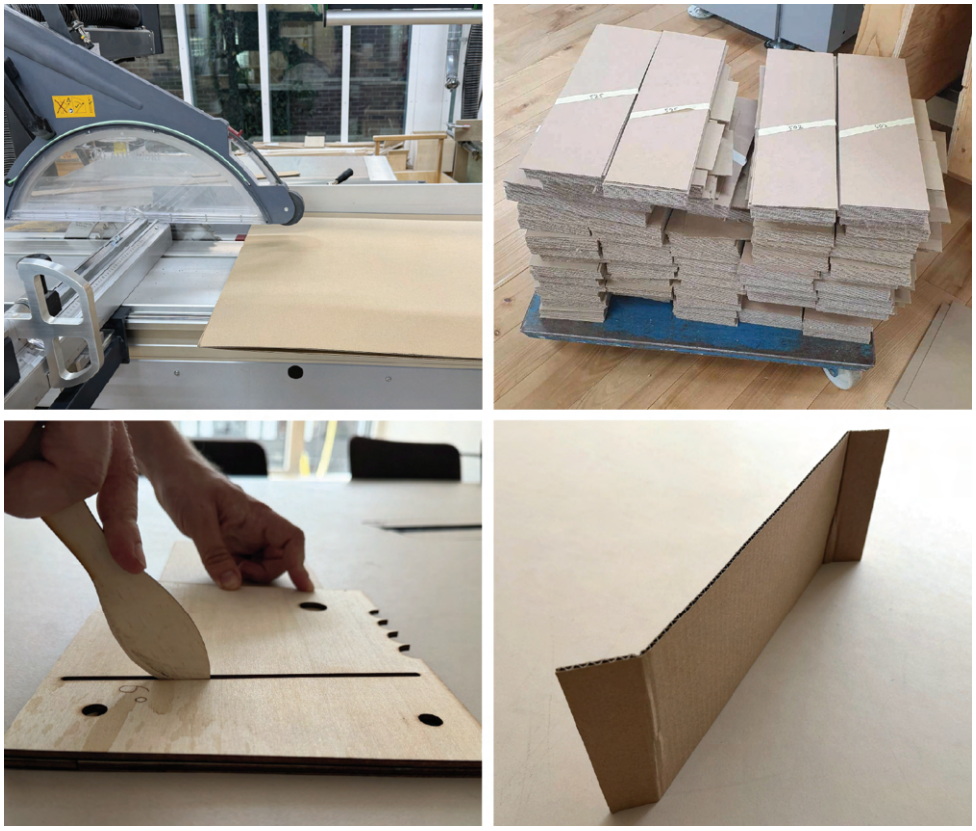

Figure 5: Fabrication sequence from cardboard sheet to finished element. Top left: cutting sheets to size using a circular saw. Top right: batch of elements after cutting. Bottom left: formation of crease lines using a creasing rig. Bottom right: completed element ready for assembly.

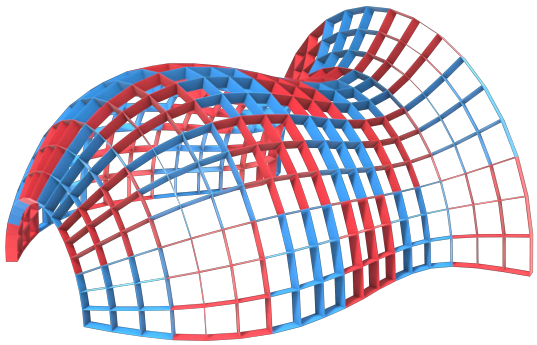

Figure 6: Division of pavilion into 36 assembly zones.

Figure 7: Incremental assembly of the first arch segment. Top left: assembly of an individual zone. Top right: joining of two zones in the arch. Bottom left: installation of bracing members in the end bay. Bottom right: completed arch segment ready for connection to subsequent arch segments.

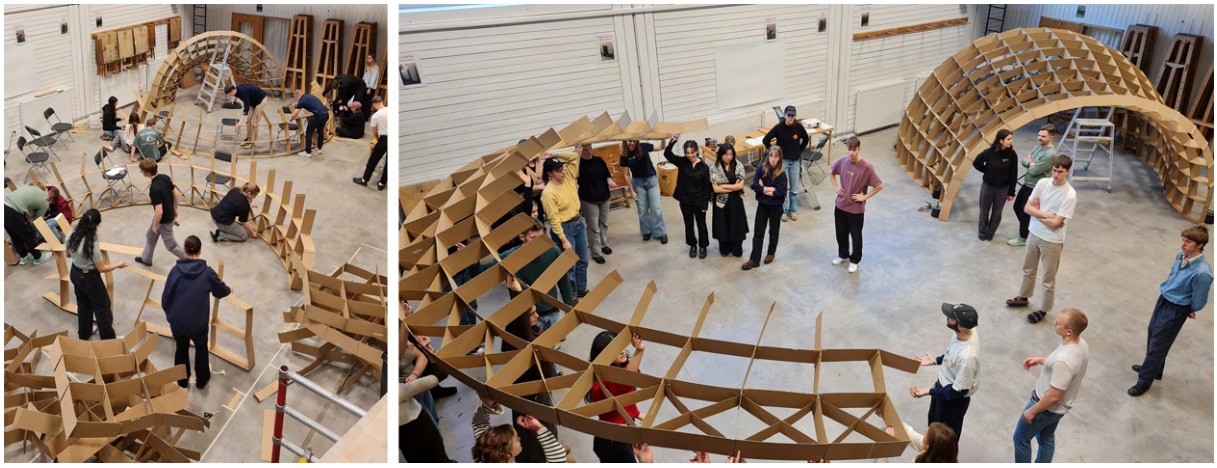

Figure 8: Incremental assembly of arch segments.

4. Results

The completed pavilion measured approximately 5.5 m in length, 5 m in width, and 2.5 m in height, comprising 20 unique member lengths and 6 unique crease angles across 684 members and 357 nodes. All primary cutting operations were completed in under two hours using a single circular saw, while labelling and creasing of all members required a further two hours. Assembly of the full structure was completed in approximately one and a half days. The completed structure maintained its intended geometry throughout assembly and remained self-supporting without observable failures during the workshop period. Local buckling and unintended deformation occurred in regions where members were forced into alignment during stapling. In several locations, connections were temporarily loosened and re-stapled to redistribute internal forces and prevent buckling.

Figure 9: Details of the completed cardboard gridshell. Left: surface geometry across a region of the pavilion. Right: close-up of a node connection showing the integrated folded end-crease detail.

5. Discussion and conclusions

The project sought to demonstrate that a doubly curved cardboard structure of this scale could be fabricated and assembled using elementary methods and limited tooling within a two-day workshop. The geometric rationalisation strategy contributed directly to the efficiency of the fabrication process. The limited set of cutting lengths allowed elements to be batch-produced prior to the workshop, reducing overall cutting time. Likewise, the six crease angles enabled reusable creasing rigs to be prepared in advance and reused across all members. During assembly, the labelling system assigned each member a unique position within the structure, reducing coordination overhead and allowing multiple student teams to work simultaneously with limited supervision.

Beyond supporting fabrication documentation, the parametric workflow proved valuable in accommodating uncertain material availability and evolving project constraints. Because the design was initially conceived around the reuse of post-consumer cardboard packaging, the geometry and discretisation strategy were developed to remain adaptable to variations in sheet dimensions and available material quantities. During the design process, the number of elements was modified shortly before fabrication in response to the quantity of available cardboard, while fabrication drawings, member labels, and quantity schedules were regenerated automatically. Although the final pavilion was constructed from uniform cardboard sheets, early prototypes fabricated from reused consumer packaging demonstrated that the cutting and creasing methodology could be applied successfully to reclaimed cardboard as well.

The project should be understood as a demonstration of how geometric rationalisation can support simple fabrication workflows within a specific educational and low-tech construction context. In other applications, the material system, connection detailing, fabrication methods, and assembly strategy would necessarily depend on the architectural, structural, and production requirements of the project.

Likewise, more rigorous structural analysis and evaluation would be required for a permanent outdoor load-bearing structure.

Nevertheless, the project illustrates how fabrication- and material-informed geometric constraints can act as a design catalyst when embedded within computational workflows. Rather than relying on precision fabrication to accommodate geometric complexity, the proposed approach reduced complexity directly at the geometric design stage. In doing so, it demonstrated that large-scale doubly curved spatial structures can be realised through simple tools, repetitive fabrication operations, and low-tech assembly processes.

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