ZipShape Mouldless Bending II

A Shift from Geometry to Experience

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Abstract. *"ZipShape is a universal method to fabricate single curved panels from any plain material without moulds" was the first statement of a paper presented at the Antwerp eCAADe conference in September 2008 (Schindler, 2008). In contrast, the paper at hand introduces ZipShape as a highly specific composite combining different materials and their characteristics. Between those two texts, a paradigm shift took place – from abstract geometrical concept to experiencing the inseparable relation of form and material behaviour. This second step of ZipShape-research was initiated by Swiss design office schindlersalmerón through several workshops with Fachschule für Holztechnik Hamburg, CITA at Royal Academy of the Fine Arts Copenhagen, Bern University of Applied Sciences BFH–AHB Biel and The Detmold School of Architecture and Interior Design.*
Keywords. *Mouldless Bending; Wood; Parametric Modelling; Digital Fabrication; Unrolling.*

INTRODUCTION

The question of making curved shapes from plain materials has challenged many architects, designers and engineers, especially since the 20th century. With the shift from serial production to individual digital fabrication at the turn of the millenium, it became tempting to make bent shapes even without the use of moulding tools.

The ZipShape method, for the first time described by Schindler (2008), is built upon a simple geometrical idea that was sketched on a train ride in 2006. A curved element is assembled from two slotted panels that interlock only when bent to the desired shape. The curvature is defined by the difference between the angles of the teeth's flanks. There are no voids or openings in the panel volume after assembly, which distinguishes the ZipShape method from wood bending methods with regular slots such as Glunz' 'Topan MDF Form' [1], Michalik's 'Cortiça' chaise longue ([2]; Reis and Wiedemann, 2010) or Kuhn and Lunin's 'Dukta' ([3]; Sauer, 2010) and concepts that allow bending of sheet metal into predefined geometry such as Tschacher's 'La Chaise' (Steffen, 2003) or ROK's 'Flat2Form' ([4]; Hensel, Kraft and Menges, 2009).

With its repetitive but individual detailing, ZipShape is predestined for generative modelling. From any given master curve, a parametric model (initially in Vectorscript, since 2010 in Grasshopper) generates the corresponding detailing. Subsequently, all distances are measured and unrolled into linear sections. All details are parametric and adjustable at any time.

Our fabrication strategy for the ZipShape panels is either cutting with a 5-axis-milling machine (using a saw-blade for the teeth flanks and a flat-nose bit for the horizontal parts) or a 3-axis mill with parallel finishing perpendicular to the tooth. Despite of the beauty of ZipShape's constructive logic, both fabrication methods take their time. Because the curvature is defined by the teeth's geometry, the mould needed during the adhesive's drying process is replaced with a large vacuum bag – the vacuum bag becomes a form-flexible mould.

FROM UNIVERSAL TO SPECIFIC

When we thought about materialization, we immediately came up with wood, because we knew that the milling machines' blades we considered appropriate for fabrication worked very well with the easy machinability of wood. We could bend some carved massive panels from MDF, plywood and massive wood down to a radius of twenty times the material thickness. This is quite impressive if compared to cold bending of wood, which may achieve a radius of about fifty times the material thickness.

Our most stunning prototype was a cantilevering rocking chair we developed during a seminar at Fachschule für Holztechnik Hamburg (Figure 1). By gluing two top layers of hard wood veneer (cherry or walnut) on a soft wood core made of spruce, we even achieved a radius of five times the material thickness. This was sufficient to receive public recognition and a number of awards, but on closer inspection the workmanship of our prototypes was not satisfying: The carved panels bent only between the teeth, which made the surfaces look polygonal. The tight radii overstressed the wood fibres at the surfaces. On the outside of a curve, fibres tended to crack while they buckled on the inside. Besides, the cold bending of the panels required the physical strength of up to three people. Even though, this strength was not always sufficient to make the two panels interlock properly. In addition, it turned out that our model at that time was not precise enough and did not exactly reflect the desired curve, as shown by Aimer (2009).

Figure 1
The 'Ziprocker', developed with R Aimer, K von Felde, O Illner, S Rehders, T Schütt and H Wolf, is a cantilevering rocking chair with a total material thickness of 30 mm, consisting of a spruce core with walnut veneer tops. The shape was derived from a car seat.
Fachschule für Holztechnik Hamburg, January 2009 (Photo: Kyeni Mbiti)

One year later we got invited to hold a workshop about digital wood joinery at CITA, the Centre for Information Technology and Architecture at the Royal Academy of Fine Arts in Copenhagen. As the geometry definition relies on the teeth's shape and the teeth are not making use of wood properties, we started our experiments with Extruded Polystyrene (XPS), which we could machine quite quickly with existing facilities on the campus. Wood was meant for a second phase to investigate structure, bending behaviour and the time-consuming gluing process with a vacuum bag – but we got captured by the experiments with ZipShape's geometry and never made it to the second phase within the three days of the workshop: Even when participants had a good cause to question the 'wood' in the workshop title, we were thrilled with the manufacturing speed and especially with the ease of bending foam without a vacuum bag.

NEW COMPOSITES

After observing that the same construction principle could behave so differently with a different material, we decided to drop ZipShape's universal status and began regarding material decisions as part of the principle.

We concluded that the toothed section of a ZipShape panel had to consist of two different areas – the teeth and the thin layer that keeps them together. The teeth should be elastic and withstand pressure to be able to define the geometry, whereas the connecting layers have to resist to tension and be bendable at the same time – a perfect match for wood's fibre structure and its anisotropic behaviour.

Wood-cork-latex composite + Veneer

As Polystyrene seemed to be inappropriate for visually and haptically attractive design, we scoured for wood based products with similar characteristics and found a product called 'Recoflex', a composite of wood, cork, and latex particles sold in large panels. Recoflex is quite elastic, but becomes stiff as soon as layers of veneer are glued on its tops. Because of its elasticity the material between the teeth can be of double thickness than in massive wood, which evens the polygonal teeth geometry to smooth surfaces (Figure 2).

During our first structural tests at Bern University for Applied Sciences, we were surprised that the choice of adhesive was the factor with greatest impact on our samples' bending resistance – some PUR adhesives were completely absorbed by the sponge-like material and seemed to have hardened it in bent state. With a span of 400 mm and a sample width of 100 mm, we detected a maximum load of about 80 kg, which made us confident to continue.

Case Study 'ZipLiege'

The wood-cork-latex composite with veneer tops was thoroughly tested with the production of two large daybeds. Both objects have a ZipShape core made of Recoflex, covered on both sides with ash veneer. The daybeds' shape was derived from the body dimensions of two potential users, taking on the idea of 'serial unique' items (Figure 3).

The most prominent improvement was the radius: The eCAADe 2008 paper specifies a minimal ratio of radius divided by material thickness rmin / t of 20 (Schindler, 2008), whereas the Recoflex composite allows a significant improvement down to a ratio of 3 (minimal radius of 75 mm with a material thickness of 24 mm).

The elasticity of the wood-cork-latex core is clearly noticeable for the daybed's user and contributes to the object's comfort. It is a surprising effect, as the veneer tops do not hint to this behaviour.

Figure 2
'Recoflex' is a composite of wood, cork, and latex particles.
It is quite elastic, but becomes very stiff as soon as layers of veneer are glued to the tops.
ETH RAPLAB, Zürich, July 2010

The two daybeds were manufactured in a Swiss carpentry. Table 1 shows a cost calculation for two scenarios: a) with manual NC code programming by the carpenter and b) with omitted NC code programming through automation. Even in scenario b) the manufacturing of one daybed takes about 15 hours, which makes it a high-priced product (Table 1).

Extruded Polystyrene Foam (XPS) + Veneer

For the 'ZipLiege' Case Study we evaluated on the 5-axis milling machine a production time of 1.1 meters per hour with a width of 0.6 m (which equals 0.7 m2/h). Again, this result is questioning ZipShape's efficiency.

A workshop at The Detmold School of Architecture and Interior Design gave us the opportunity to investigate a production concept that goes without a milling machine. We used common extruded polystyrene (XPS) for the core in combination with a large CNC foam cutter to cut the teeth into the panels. As the hot wire cuts the whole ZipShape profile in one go without changing the tool, the process accelerated significantly to a production time of 4.4 meters per hour – four times faster than the 5-axis milling machine.

The foam cutter is able to cut any ruled surface. Consequently, we experimented extensively with edge fillets and advanced interlocking systems. The hot wire is especially interesting for twisted geometries, where teeth flanks are not planar and therefore cannot be sawn (Figure 4). To make the XPS panels resistant to tension, we used once more wood veneer as top layers on both faces.

Figure 3
The 'ZipLiege' is made of an 18mm Recoflex core covered with ash veneers. The shape is derived from body dimensions. It was 5-axis sawn at Schreinerei Schnidrig in Visp and vacuum-glued at BFH–AHB in Biel.
Designers' Saturday 2010, Langenthal, November 2010 (Photo: Kyeni Mbiti)

Table 1
Cost analysis of case study 'ZipLiege', based on calculations by Schreinerei Schnidrig, Visp

Work step	a) Cost Portion	a) Hours / Daybed	b) Cost Portion	b) Hours / Daybed
1 Manual NC code programming	29 %	8	–	–
2 CNC 5-axis milling machine cost	29 %	4	41 %	4
3 Material cost	11 %	–	15 %	–
4 Gluing veneers and edges, bending	8 %	2	12 %	2
5 Surface Treatment	16%	7	23 %	7
6 Others	7 %	2	9 %	2
TOTAL		23		15

Polystyrene is quickly and easily workable, light and inexpensive. However, in terms of surface feel, stability and sustainability it is not comparable to wood or wood based products.

EXTENSIONS TO THE PARAMETRIC MODEL

Tolerance and Resilience

To be able to match a ZipShape sample with its desired curvature, a number of material characteristics had to be respected and included in the parametric model. In the first place, a continuous tolerance distance had to be established between the two slotted panels. This distance depends not only on the material characteristics of the chosen adhesive (e.g. foaming properties), but as well on the chosen production technology. For instance, it turned out that sawing the teeth requires less tolerance than milling – and even the sharpness of the respective tool's blade(s) exerts an influence: We experienced during a day of milling with the same bit that the pieces fabricated in the morning fit smoothly, while the ones produced in the afternoon could hardly be assembled.

The second factor is material resilience – a factor that had to be included into the parametric model, especially for the elastic Recoflex: To work against material's resilience, an experimentally determined 'resilience factor' exaggerates the curvature in the unrolled surfaces.

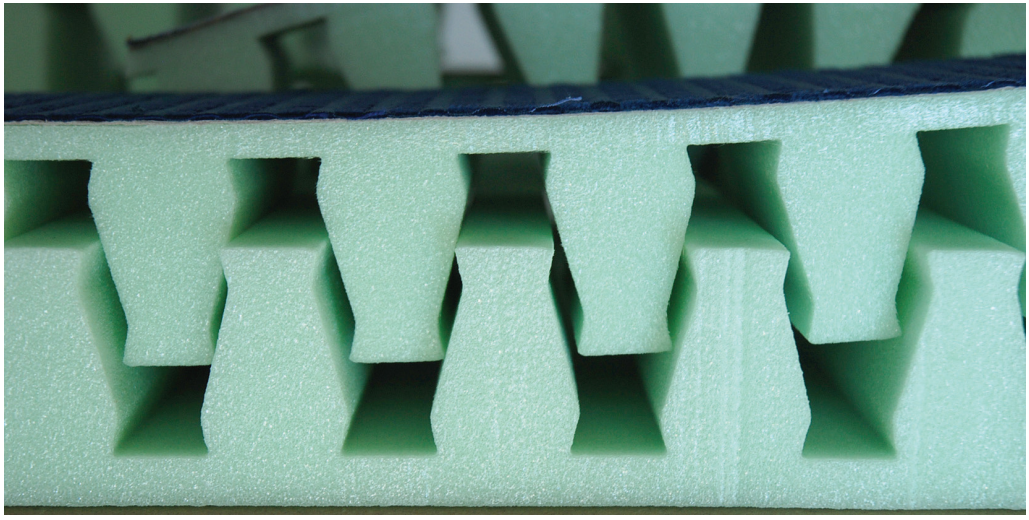

Figure 4
Hot-wire-cut Snap-Fit Joint System by J Bieniek, F Nienhaus , L A Pinkcombe and A Wood
The Detmold School of Architecture in collaboration with University of Florida, May 2011

Respecting both tolerance and resilience, the curvature of our ZipShape-prototypes came very close to a 1:1 paper printout of the desired curve (Figure 5). But for every new constellation of material, adhesive and production technology, those factors have to be evaluated by experiments.

From bent to twisted

For an exhibition at Designers' Saturday 2010 in Langenthal Switzerland, we developed a large sculptural object meant to test ZipShape's spatial potential and its capacity to cover not only bent but as also twisted geometries.

Our starting point was the bending behaviour of a paper strip, as investigated recently for instance by Nettelbladt [5] and Lachauer [6]. These spatial geometries seemed especially interesting to us, as unrolled paper-strip-like ribbons can be nested in parallel on panels without any waste (Figure 6). To realize the object, we developed an extension to the parametric model that calculates a developable linear paper-strip into any given spatial curve – identical to the bending behaviour of a manually deformed paper strip. The design input is reduced to a spatial curve, while the formal composition becomes a derivable (but for us as designers not precisely foreseeable) part of the method.

After Designers' Saturday, the dismountable 'ZipSculpture' was shown in November 2010 on the occasion of the 'Open Day' at BFH–AHB in Biel (Figure 7) and in February 2011 as part of the exhibition 'The Art of Trees – A Forest Gallery' at the UN Palace of Nations in Geneva.

CONCLUSIONS

The eCAADe 2008 paper proposed to investigate further "universal fabrication of ruled surfaces", "reducing the radius" and "testing other materials than wood and wood composites" (Schindler, 2008). Those three points have been worked further. There is no other cold bending method known to the authors that renders possible a comparable ratio of radius and material thickness. While working towards that goal, we reflected our results and drew the following conclusions:

From geometry to experience

Having started from an abstract geometric model, we learned first to take the fabrication constraints

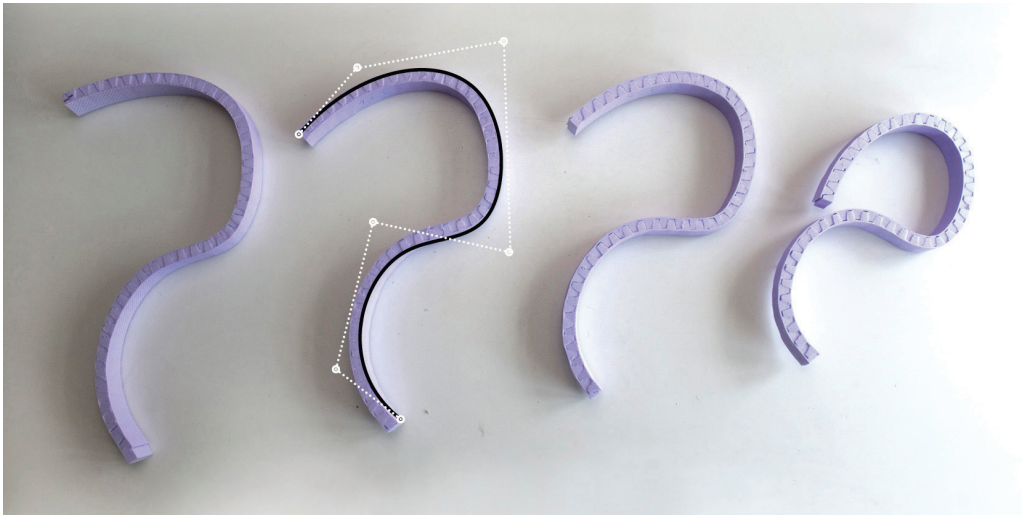

Figure 5
Four XPS samples with an increasing 'resiliance factor' that exaggerates the curvature in the unrolled surfaces. The black curve displayed on top of the second sample is the original master curve. ETH RAPLAB, Zürich, August 2010

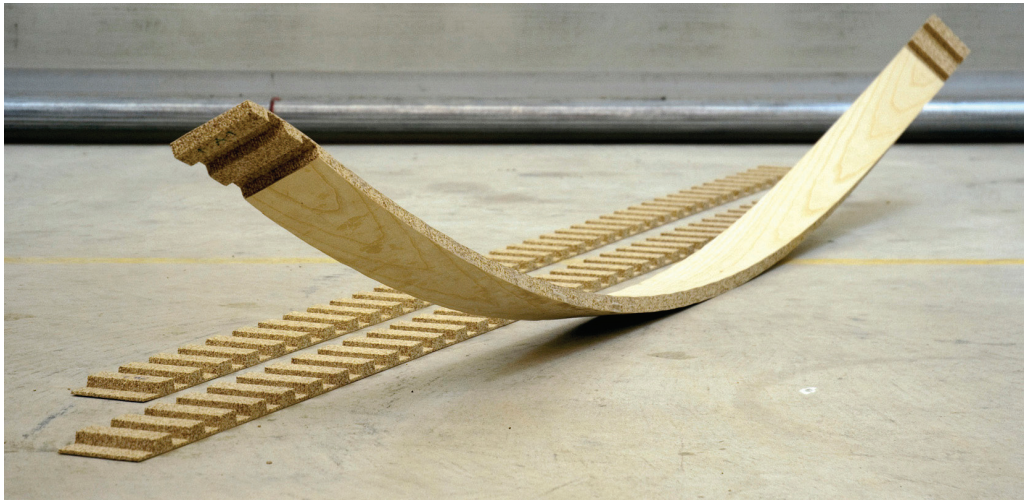

Figure 6
Twisted geometries from developable strips.
BFH–AHB, Biel, October 2010.

Figure 7
The 'ZipSculpture' as exhibited at Open Day in Biel in November 2010 is a continuous, developable ribbon assembled from eight elements with 300 individual tooth geometries and a total length of almost 20 meters.
It could be realized with the help of A Rosenkranz, S Kraft and C Rehm.
BFH–AHB, Biel, November 2010.

into account and second to design actively with material characteristics – recognizing form, material and production technology as an inseparable system. We were especially surprised that the effects of material and fabrication factors could not be precisely predicted and had to be determined experimentally. As soon as we respected material and production technology, we left our consistent geometrical model behind.

From school to market, or: The journey is the reward

At present, the project may be regarded as quite an academic success, counting four invited workshops at different schools and a multitude of invited lectures, complemented with a number of awards. Its descriptive way of interweaving material and information processing seems to represent a contemporary mindset in architecture and design.

However, applying ZipShape to the market is a process more demanding than expected. The perfect material combination has not been found yet. It seems that the technology's strength is not replacing existing technologies in existing market fields. We believe that ZipShape's potential is inventing new applications based on the specific characteristics of the method.

ACKNOWLEDGEMENTS

schindlersalmerón is a private design office with limited research capacity. Without the opportunity to hold workshops at a number of schools, we could not have conducted this project. We are thankful to everybody who supported us – in particular: Mark Wendt from Fachschule für Holztechnik Hamburg gave us the opportunity to realize a ZipShape rocking chair, designed and built by his class of wood engineers. Mette Ramsgard Thomsen and Martin Tamke from CITA in Copenhagen reactivated the project by inviting us for a workshop with the Digital Crafting Network. Yves Ebnöther, Head of RAP-LAB at ETH Zürich, allowed us to use his facilities to fabricate prototypes. Heiko Thömen and his team at Bern University of Applied Sciences BFH–AHB enabled the realization of the ZipSculpture. Marco Hemmerling from The Detmold School of Architecture and Interior Design in collaboration with Step Four GmbH offered us the possibility to research fabrication with hot wire cutting.

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