**Stone and Oak - the ‘Glücksrad’ of Basel Cathedral**

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**ABSTRACT:** The so-called ‘Glücksrad’ – wheel of fortune – is one of Basel cathedral’s main attractions. The present study aims to examine the central wooden ‘rota’ from 1225 with its building and restoration history. The preserved original fragments of the dismantled structure provide the basis for an analysis of material, details and building process as well as the relationship to contemporary stone structures. The rota’s structural system is discussed. Fractures and deformations of the work pieces can be explained as results of the famous Basel earthquake of 1356.

**DESCRIPTION OF THE ROTA**

The ‘rota’ – ‘wheel’ or ‘rose’ window (Knapp, 1970) - is inserted in the surrounding masonry of the cathedrals’s north transept (Fig.1). It consists of the internal ring around the central oculus, the posts and the external ring. The wooden structure is composed of only two types of work pieces: the arcs of the internal ring and the combined pieces of posts – the spokes of the wheel – with two half-arcades attached. The internal ring is penetrated by a series of 16 apertures in the posts’ axes. Small oculi and diagonally positioned squares alternate. The window’s posts are set on the internal rings’ extrados; they are carved with half-columns with base and capital on the outside. The window openings in between the posts close with a series of arcades: the external ring or arcade ring. The pendentifs directly above the capitals are also penetrated by a series of Oculi. The rota is inserted in the transept’s masonry with a strength of about 1,25m. The richly carved stones can be described as the window’s embrasure. The famous cycle of rising and falling figures – the name-giving ‘wheel of fortune’ is set on the outside, the main viewing side. The height of the deformed rota (DB b) is about 5,05m, its width is ca. 5,45m. The profiles of the internal ring have a depth of 13cm, the ring’s height is about 40cm. The dimension of the interior oculus adds up to 2,05m (height) x 2,17m (width). The examined ‘rota’ was originally assembled as an oak wood structure. Although the medieval construction was dismantled during a restoration campaign in 1885, it was partially preserved and stored in two depots in Basel, the Museum ‘Kleines Klingenthal’ and the Depot of the ‘Historisches Museum’. The structure was replaced with a stone copy which follows its predecessor in aspects of dimension and ornament. Construction details and stereotomy differ.

**BUILDING HISTORY**

**Erection in the early 13th century**

In the Nineteenth century, the former parson of Basel cathedral, Emanuel LaRoche, was the first to date the rota back to the time “around 1200” (SB a). Thus, he contextualized the window with the part late-romanesque, part gothic-influenced new cathedral building, the so-called ‘3. Münster’. Dendrochronologic evidence from the last years confirm the dating: the relevant specimens from the posts could be dated into the years 1224 and 1225 (DB a). Since every aperture of the wheel is supplied with rebates on the inside, it can
be assumed that the rota was fully glazed. Additional incisions on the inside indicate additional cross-irons acting as support for the glazing. The irons are not preserved, but the historic constructions of the windows at Marienstatt Abbey or of the main nave’s windows at the nearby cathedral of Strasbourg can give an idea of their design and structure (Elenz, 1998).

Figure 1: Hypothetical reconstruction of the wooden rota on the basis of a photogrammetric survey of the facade (DB b). Dotted lines mark the baroque iron rods. The arrangement of the posts is hypothetic.

Historic repairs

Until its replacement in 1895, the ‘Glücksrad’ was subject to several restoration campaigns. The oldest and most decisive structural intervention was a result of the destructions caused by the devastating earthquake on 18th October in 1356 (Meyer, 2005). Though parts of the cathedral collapsed, the flexible wooden framework of the ‘Glücksrad’ and major parts of the north transepts masonry endured. As a result of the earthquake, the geometry of the rota was compressed from a circle with a diameter of 5.25m to an ellipse (SB b, Reese to Dr. C. Burckhardt, 30. May 1885). A strong crack in the transept’s masonry as well as a 30 cm lowering of the stone courses above the rota still bears witness to the earthquake. On the wooden structure, several wrought iron strips nailed onto cracks and fissures served as makeshift safety devices.

A general restoration of the medieval wooden structure was not carried out until the great restoration campaign of the cathedral in 1761-1771 (DB a). In course of the works, parts of the stone embrasure were renewed. Together with the replacement of damaged ashlar, some parts of the wooden wheel were substituted with copies. One arc of the four-part internal ring was replaced. Additionally a number of posts was renewed. Whereas the renewal of the stone figures was carried out in baroque forms, the replacement of the wooden parts meticulously followed the medieval design (Fig.2). On the wheel’s fragments, traces of an additional wrought iron safety device can be found: drill holes in the interior ring as well as traces of rust indicate a supporting structure consisting of four iron rods. The rods were arranged crosswise, i.e. two rods ran horizontally and two rods ran vertically, each at one third of the full diameter (Fig.1). To judge from the traces on the wood’s surface, every iron rod was connected to the internal ring with two or three bolts with washers.
A summary recording of the rota and its glazing in 1775 is preserved on p. 25 of Emanuel Büchel’s “Sammlung der Merkwürdigkeiten von Basel”. Unfortunately, construction details or deformations are not represented. Still, the sketch gives a good general overview of the glazing: the external ring, the arcades and the glazing between the posts are filled with a – probably translucent – small-sectioned, diamond-shaped glazing. The central oculus shows eight radial, irregular iron rods holding a central, circular plate with the Basel coat of arms.

Figure 2: Details of the baroque posts (a) and the medieval posts (b) in comparison. The original details are meticulously copied, the baroque base’s irregularity adapts to the rota’s deformation.

Dismantling and replacement 1885

The medieval wooden rota with its baroque addition persisted in situ until 1885: In the years from 1880 to 1885, a further general restoration of Basel cathedral was undertaken. The preliminary examinations for the northern transept’s restoration were carried out in autumn 1884. After a first analysis, the responsible master builder, Kantonsbaumeister Reese, assumed that the main works would be carried out on the stone figures. On the wooden structure, only minor repairs were planned (SB a, Reese to Dr. C. Burckhardt, 6. December.1884). After the erection of the scaffolding, it became clear that ‘the wooden tracery window [was] in a considerably worse state than thought’ (SB c, 19. May.1885, 21. Session). Without formal consent of the ‘Münsterbaukommision’ (Cathedral building committee), the wooden structure was dismantled under Reeses supervision in the first weeks of May. During the Committee’s following session, it was discussed in detail if “the tracery was only to be repaired, or if it should be replaced; and, if the latter were the case, the copy should be carried out in stone”. Master builder Reese proposed to implement a stone copy “supported by a supplementary iron construction […] with U-Profile that should remain invisible” (SB d, 6.July 1885, p.10-11). After some approximate numeric calculations (which are not preserved), Reese decided to dispense with the iron construction (SB b, Reese to Dr. C. Burckhardt, 30. May 1885). After some further consultation with the famous Basel art historian Jakob Burckhardt it was decided to replace the medieval structure with an exact stone copy. The copy was crafted in July 1885, the parts of the wooden model were stored in several depots in Basel.

BUILDING CONSTRUCTION

Elements and Joints

The oaken structure is composed of only two types of work pieces:

a) Arcs of the internal ring

The internal ring consisted of four wooden arcs of similar size and design. Every single part has a length of five “axes” with apertures and connections to the posts. In every arc’s centre a square aperture is positioned, flanked by two oculi. The following square apertures are situated in the centre of the overlapping joints between two adjacent arcs. The oculis’ diameter as well as the inner width of the squares is about 18cm; every aperture is carved with a small diagonal chamfering on the outside and a rebate for the glazing on the inside. The wood fibres of the arcs tangentially to the circle’s perimeter.

b) Posts with the external ring attached.

Every work piece consists of one post with base and capital and two half-arcades attached. The sixteen posts stand perpendicular on the internal ring’s perimeter. The posts’ profiles are designed as square sections with a half-column added on the outside, the bases of the posts are carved as upside-down cushion-capitals with an attic base on top. The posts’ capitals are carried out as stylized corinthian capitals. The cross section of the posts corresponds with about 18cm to the inner width of the apertures set below the posts in the internal ring. The series of semicircular arcades is arrayed above the posts; their diameter is about 65-70 at the capitals’ level. The pendentifs directly above the capitals are also penetrated by a series of Oculi, their inner width is, again, about 18cm. The wood fibres are oriented parallel to the posts’ orientation – in aspects of masonry, they could be addressed as ‘en-délit’-elements.

With these different parts, only three different types of joints have to be analyzed:
The joints of the arcs are carved as standing half-lap scarf joints. Both adjoining arc parts are worked off to their half depth at the joint. The front sides are cut diagonal. In contrast to traditional timber workmanship, the laps are connected not with wooden pegs but with several wrought iron elements; additionally, the half laps are decidedly impaired by the unusual layout with central square apertures. The scarf joints are positioned over and around every second square aperture in the internal ring. Thus, the apertures had to be cut precisely and accurately fitting into both half-laps. On the window’s exterior, the bolt’s head is forged with a round head. The bolt’s profile with a diameter of 1.9cm is constant over its full length; its interior end-piece has a short protruding nail-like point and is bent. Two bolts are situated between the aperture and the ring’s extrados, one underneath the opening near the intrados.

The details of the baroque additions to the wheel differ from their medieval predecessors. One of the four arcs was replaced. The new piece projects over the original length, thus cutting into the adjoining arcs. Both scarf joints with the adjacent medieval parts were trimmed; the new joints are blunt without any regular timber detailing. For safeguarding the joint, a short iron strip was nailed onto the interior of one of the blunt joints. The renouncement of any regular timber-workmanship indenting with the medieval parts confirms the existence of an additional supporting system onto which old and new parts were fastened.

The joint between the arcs and the posts is, in aspects of traditional timber workmanship, unusual. The post is standing on the rota’s internal ring; the single pieces are, again, connected with iron ‘dowels’. The execution is analogous to the iron bolts of the arcs’ scarf joints. These dowels were, after a first temporary array of the single parts, inserted into the joints from below through the apertures in the internal ring. The ‘nail head’ comes to rest in the apex of the Oculi or the diagonal squares. Thus the blunt joint of posts and arcs is secured with an internal, retractable iron dowel.

No regular joint does exist between the external ring’s work pieces: the single parts of the arcades are not connected but simply abutted against each other. The single work pieces were – as can be seen on a sketch drawing made by master builder Reese - inserted into a groove in the masonry. The groove’s depth is about 10-15cm. Traces on the surviving fragments confirm the detail: On every single work piece, a white marking runs parallel to the extrados with spacing of about 12cm. Above the marking, the ‘protruding’ parts are less affected by weathering; the dimension of the protrusion fits with the assumed depth of the groove.

Implementation and construction sequence

The examination of the details is closely connected with the analysis of the construction sequence. Comparable to the latter gothic stone traceries, two alternative solutions for the construction sequence are possible. One is to erect the ambient masonry, and to insert the prefabricated wooden structure into the completed circular recess. On the other hand, an ‘integrated’ construction sequence can be discussed: The bottom half of the circular recess is prepared as ‘mounting’ for the wooden wheel. As soon as a sufficient height of the enclosing walls is accomplished, the wheel can be inserted. It has to be temporarily braced in cross direction. The top half of the wheel can act as ‘dead sheathing’ for the upper layers of the masonry during the construction sequence. Both alternative solutions create several technical difficulties (Mohrmann, Ungewitter, 1901): The usage of the wooden wheels as ‘dead sheathing’ renders necessary a temporary bracing in cross-direction. For the bracing, further scaffolding on both sides of the transept’s wall is required. On the other hand, the subsequent insertion of the rota into a prepared recess leads to geometric problems – due to the insertion into a circular groove, the diameter of the wheel is larger than the diameter of the opening.
In spite of this objection, the details indicate a subsequent insertion of the wheel into the finished masonry of gable and embrasure. This enables to reconstruct the hypothetic construction sequence: The opening for the wooden wheel was left open during the construction of the transept’s walls. A precise, stable centering had to remain in place until the setting of the lime mortar. After removal of the centering, the prefabricated rota could be inserted following a precise schedule. Primarily, the work pieces of the external ring – posts with attached arcades – had to be inserted into the groove and temporarily fastened. After insertion of every post, the internal ring could be set in, ‘locking’ the posts in the groove. For a permanent stabilization, the iron bolts were inserted into the apertures and driven into the predrilled holes in the ring and the posts’ base.

Hence, the structurally ‘problematic’ apertures in the internal ring directly underneath the posts can be explained as auxiliary devices for the construction sequence. Further evidence gives the apparent irregularity of the external ring’s extrados: if it had acted as centering for the upper layers of masonry, a precise und flush finish of the extrados would have been mandatory. Likewise, the lack of sound joints between the parts of the external ring makes its use as self-supporting centering unlikely. Similar practice can be documented for the future gothic building practice; i.e. for Regensburg (Hubel, Schuller, 1995) or Troyes Cathedral (Murray, 1987).

Stone and Oak – A comparison of tracery structures

The construction details are rational; their functionality is documented by the structure’s durability. Nonetheless, the divergence from traditional timber workmanship is conspicuous. A number of details at the Basel ‘Glücksrad’ find close analogies in contemporary masonry structures. Obviously, the Basel rota follows the model of its stone predecessors in aspects of design as well as in detailing. Unfortunately, few of the 12th century rotas like Beauvais or Verona (Kobler, 1987) survive as originals, and even fewer were examined with a view on construction details. The technical developments can only be deduced from the later examples of the 13th century:

The connection of the post with the internal ring with an inserted wrought iron dowel shows a remarkable similarity to contemporary masonry practice. Latest since the erection of the great Rose window of Lausanne Cathedral around 1205, the connection of stressed stone tracery elements was executed with inserted iron pins. Molten lead was cast into the open joint and fixed the central iron pin (Barthel, Beckh, 2006). The application of molten lead was obviously not feasible on a wooden structure. Still, the insertion of a central wrought iron pin into the joints of two adjacent work pieces indicates a technology transfer from the wooden rota’s stone models. Similar analogies can be found for the insertion of the wheel into a groove in the embrasure. It can be compared to the first “real” gothic tracery windows, developed by Jean d’Orbais at the building site of Reims Cathedral around 1220: The tracery in the window crown is separated from the adjacent masonry with a con-

Figures 4 and 5: Connection between post and internal ring, Insertion into the embrasure
tinuous joint. Both parts interlock: the extrados of the tracery is built with a protruding ‘tenon’ that is inserted into a ‘mortice’ or groove in the top masonry, the detail is already drawn in Villard’s sketch book. This typical construction detail exists in several different shapes. In spite of the fundamental analogies between the ‘Glücksrad’ and the early stone traceries in the aftermath of Reims, it seems unlikely that the traceries of Reims and the Ile de France served as model for the building site of Basel. Though the Reims ambulatory windows were designed and built before 1220, about five years before the erection of the Basel Rota, successive constructions emerged even in France not until around 1225. As the Basel wheel is formally modelled on older, late-romanesque predecessors, it cannot be interpreted as development of the gothic archetype ‘tracery window’. A comparison with predecessors like Lausanne indicates an analogous development in Basel and Reims: the construction techniques that enabled Jean d’Orbais to develop the new ‘tracery’ were already available and approved of in the late 12th century. The tracery in Reims was no new technique, it used existing models and details in a new context and combination. The Basel rota shows the application of the same basic details and principles on a diverging model with a different building material. In contrast to the Reims model, the rota of Basel did not find any successors. With the adoption of the ‘modern’ gothic model, the alternative option of a different tradition was outdated.

STRUCTURAL ANALYSIS

Structural system

The oak rota served – as any other tracery or rose window – not only as ornament but also as an integral part of the cathedral’s structural system (Barthel, Maus, Jagfeld, Scherbaum, 2006). The exposed setting under the north gables makes it subject to considerable wind loads that have to be absorbed by the wooden, 15-20cm strong wheel. For the examination of the load-bearing structure, two different models can be discussed. Additionally, it has to be distinguished between the original system and the system after the grave damage and deformation in the earthquake of 1356.

a) Original Structural System 1225 - 1356

Model A

In the comprehensive 19th-century treatises on the theory of gothic structures as the ‘Lehrbuch der gothischen Konstruktionen’ (Mohrmann, Ungewitter, 1901), a model for the structural analysis of stone tracery was developed: “it can be assumed, that the wind […] acts on the posts similar to the load on a flat arch. In consequence, the post’s end pieces exert forces similar to a vault’s thrust.” This theory on ‘standing’ stone tracery windows could be verified with modern FE modeling during the restoration of the eastern window of St. Georg in Nördlingen (Barthel, Schiemann, Jagfeld, 2003). Its validation for rose windows was examined in the last years by J. Heyman, J. Heyman, 2002]. Whereas in ‘standing’ tracery windows the parallel post act as single ‘beams’, the radial array of posts in a rose window creates a certain “pattern of compressive forces […] within the window”. Without any reference to the material, Heyman’s assumptions on the structural system of a ‘simple’ rota with an external ring, posts and an internal ring can be applied onto the Basel window:
- The posts transfer ‘horizontal’ (in the case of a rota: parallel to the posts) forces onto the adjacent masonry and onto the internal ring.
- The internal ring acts as a compression member taking up the compressive forces from the posts.
- The existence of an open oculus in the window’s centre enables the structure to absorb a certain amount of deformation. Traversing post would, in case of a deformation of the window, break.

With a view on the details and the material, the application of this model on the wooden wheel does not seem likely: “The model works only on condition that all joints are very stiff and no gaps or cracks interrupt the flow of forces. The shear forces also have to be transmitted at the joints.” (Barthel, Schiemann, Jagfeld, 2003). The wooden structure with its joints was presumably initially not able to provide the necessary stiffness.

Model B

For the original structural system before the grave deformations from 1356, an alternative model can be developed: The posts and the external ring are carved as combined, homogenous work pieces. Every part is inserted into a groove in the embrasure; the joint is friction-locked. Hence, the single projecting posts can be interpreted as cantilevers with a clamped support in the masonry. In the model, the barycentre of the triangular work pieces would be ca. 80cm from the embrasure, with a wind load of about 1.5kN on each member. The internal ring could act as a fastening support for the radial array of posts. This model is material specific; a cantilevered action would hardly be possible on a stone structure of similar dimensions. However, doubts remain with regard to the unequal dimensions of the ‘tenon’ inserted in the groove ‘mortice’. Both models described are an approximation. Due to the latter-time deformations and the subsequent dismantling of the wheel, the original structural system can only be theoretically discussed.

b) Structural System after the earthquake of 1356 until 1763

Originally, no vertical loads from the gable’s masonry were transmitted onto the wheel (see above, ‘building sequence’). As a result of the earthquake, the top stone courses lowered onto the wooden structure which was vertically compressed. Vertical loads from the masonry were transferred onto the rota. This enabled a
change in the structural system: the additional loads acted as a kind of vertical ‘prestressing’ providing additional stiffness. In the vertical section, a load transfer as described in model A with a ‘flat-arch-action’ became possible.

c) Structural System between 1763 and 1895

During the baroque renovations 1761-71, a supplementary iron construction acting as a support for the wind loads was added on the inside. It can be assumed that this construction stayed in place until the replacement of the rota in 1895. Unfortunately, master builder Reese’s original calculations for the replacement stone wheel do not survive. For the existing structure, the validity of model A can be assumed.

Damage and Cause

In course of the examinations in 1884/85 the rota’s basic fabric was judged fundamentally instable, and subsequently dismantled. The grave damage can still be discerned on the surviving fragments:

Only parts of the external ring and the posts are preserved, the internal ring is still complete. It seems probable, that especially the bottom parts of the external ring were so much corrupted that preservation did not seem reasonable. These pieces were subject to heavy exposition with driving rain from the cornices. Additionally, water could leak into the groove in the bottom half, constant humidity lead to mould and decay. Apart from problems arising from insufficient building maintenance, the wooden fragments show a number of cracks and fissures that give insight into its structural system:
Internal Ring (Fig. 6, 7)

In the three surviving arcs of the internal ring, fractures and fissures can be discerned. A distinction has to be made between the fissures parallel to the fibre orientation resulting from wood shrinkage processes and “structural” cracks orthogonal to the arc line. The top arc shows a conspicuous fracture of the profile in the remaining profile underneath the topmost oculus; the side arcs show corresponding cracks on the left and right extrados. The fractures can be explained as results of the 1356 deformations: the deformation of the masonry recess from circle to ellipse is imposed on the internal ring via the posts. Due to the blunt open joints between its adjacent parts, the external ring could not absorb the loads from the gable masonry; the loads were transmitted onto the internal ring. The arc radius of the top and bottom arc increased, the radius of the left and right arc decreased. The arc-parallel wood fibres on the intrados of the top and bottom part and of the extrados of the side parts could not absorb the tensile loads and fractured the affected arcs’ sectors acted as hinges.

External Ring (Fig. 7)

The half-arcades of the externals ring’s parts are cracked radially, parallel to the wood fibres. The damage results from the rota’s deformation as well: the deformation of the external ring from circle to ellipse lead to an alteration of the tangents’ angles. The posts’ bases were fixed on the extrados of the internal ring and could not adapt freely to the external ring’s deformation. Thus, the protruding half-arcades were twisted and forced against the stone embrasure. Therefore, the protruding parts sheared off parallel to the fibre orientation. The baroque additions do not show similar damage.

CONCLUSIONS

Few rotas or original tracery windows from the early 13th century survive, and of these, the Basel ‘Glücksrad’ is the only known large-scale wooden structure. Thanks to its flexibility, the rota survived the great 1356 earthquake. Damage of the north transept’s masonry lead to a transfer of loads onto the wooden wheel. The structure prevailed but the single parts were fractured and deformed. The rota’s preserved fragments are an important document of the development of details and constructions.

The analogies between the oaken structure and contemporary stone models give insight into the transfer of knowledge between the building sites. The contemporary independent development of gothic tracery in the Ile de France rota shows the application of the same basic details and principles and refers to the same basic models.

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