8th International Congress on Construction History - Zurich

POLYNORM _ Dutch modular construction of the 1950s entirely made of steel sheet

Nicolas Grandjean, Agnès Collaud, André Jeker, Reto Mosimann and Séréna Vanbutsele.

Institute TRANSFORM, HEIA-FR, HES-SO University of Applied Sciences and Arts Western Switzerland

Abstract: Material-saving lightweight construction systems for buildings were a recurring theme in the first half of the 20th century and still are today for reasons of sustainability. The construction system developed by NV POLYNORM in Holland after the Second World War fits well into this category of construction systems. With NV Ontwikkelingsmaatschappij POLYNORM, mechanical engineer Alexander Horowitz developed and industrialized a comprehensive construction system for residential buildings and warehouses. The versatile processing and use of steel sheet is characteristic of the system. Due to the little material thickness of the sheets, a surprisingly high material efficiency and a low total weight are achieved. Another important feature of the construction system is that it can be raised by means of dry construction method, which allows easy and fast assembly and complete disassembly of the buildings. The present work focuses on the hall construction of POLYNORM with a structure entirely made of folded steel sheets and the corresponding façade cladding.

Introduction

The dismantling of a warehouse as part of the investigation into the circular economy by the Institute Transform, HEIA-Fribourg has led to the successive discovery of an astonishing building system from the 1950s. What was initially perceived as a super light building structure made of folded steel sheets turned out to be a complete, well thought-out building system.

POLYNORM started in the late 1940s with the development of industrially manufactured residential buildings for reconstruction after World War II. The company continuously expanded and modified the system until construction activity slowly came to a standstill in the 1960s. In addition to residential construction, the industrial halls, warehouses and projects for school buildings were increasingly added (tuencyclopedie.nl) (Bouwmeester, Timmermans, Post 2006, 32). Common and characteristic for these very different construction tasks are the use of industrially building materials such as steel sheet and concrete, prefabrication in the factory and consistent assembly as dry construction. The diversity of the system and the continuous development are manifested in a great number of patents.

Today, systematic survey on the POLYNORM construction system have only been carried out and published at the TU Eindhoven (2006). This investigation, which also include a dismantling and temporary reconstruction of one unit, focus on the residential buildings erected in Eindhoven in 1951. The aim of the present survey is to investigate the hall constructions based on the truss type-72.

Today, based on the TU Eindhoven survey and cross checked with extended internet research and contact with property owners, we have been able to track down six POLYNORM halls. Fife of them are conceived with the type-72 truss. In chronological order, they were built and partially preserved at the following locations.

- 1951 Bunschoten, NL. Polynorm factory, with old type of girder. Burned down in 1952. (Jungo. 2023. 8)
- Bunschoten, NL. Reconstruction Polynorm factory. (voestalpine.com)
- 1953 Châteauroux, F. Storage halls for the US Air Force and NATO. Existing, today with civilian use.
- 1957 Bergeyk, NL. Hangar for Weverij De Ploeg. Existing.
- 1957 Neuhausen am Rheinfall, CH. IVF hall. Demolished in 2018.
- 1958 Fribourg, CH. CAFAG warehouse. Dismantled and stored in 2022.

As a physical testimonial, the hall in Fribourg was carefully measured, documented, dismantled and stored. The hall is a central source of information for this study, even if it is a special case in certain aspects. The ambition of the POLYNORM research project is to rebuilt the hall as a demonstration for reuse in construction. (Fig. 1)

In addition to the detailed examination of the original structure of Fribourg, the POLYNORM system and its individual parts are being researched on the basis of registered patents and the few original. The comparison of original components of Fribourg and historical documents provide information about the adaptability of this building system.

Figure 1. Interior view of the POLYNORM hall in Fribourg before dismantling (Transform 2021).

1. Origin of POLYNORM modular construction

POLYNORM is the name of a historical construction system that is no longer manufactured today. The system was developed in Holland in the years after the Second World War by mechanical engineers and construction specialists (Bouwmeester, Timmermans, Post 2006, 13) (nl.wikipedia). The main characteristic of the system is that the individual components were prefabricated using advanced industrial processes and could be assembled on site using only dry construction methods.

NV POLYNORM was well experienced and equipped to process metal sheet. It is therefore not surprising that the majority of the design solutions for the building structure and other components are based on processed steel sheet. Development, production and experience are concentrated around the specific manufacturing technology with the same basic sheet material.

From today's perspective, the result is an astonishingly well-thought-out construction system that makes extremely economical use of the materials used and can be completely dismantled without generating waste.

1.1. The NV POLYNORM company

The remarkable system of the construction and the identification of a truss girder discovered in Fribourg led to research into the history of the POLYNORM company, including possible patents. In fact, several patents, related to the POLYNORM construction system, are registered by the European Patent Office. The patents are registered in the name of the company "NV Ontwikkelingsmaatschappij Polynorm" from Bunschoten, NL. The mechanical engineer Alexandre Horowitz is named as the relevant developer.

Alexandre Sacha Horowitz (1904-1982) studied mechanical and electrical engineering at Delft University of Technology. From 1929 to 1948, he worked as a development engineer at Philips. The most well-known development from this period, for which Horowitz is named as the inventor, is the Philishave electric razor. In 1948, he co-founded the company NV POLYNORM for industrialized construction. From 1958 to 1974, he was professor of mechanical processes at the Technical University of Eindhoven. Horowitz was also the co-founder of a number of companies in the field of mechanical engineering and agricultural machinery. He is the author of more than 130 patent applications (Bouwmeester, Timmermans, Post 2006, 16-17) (www.tudelft.nl) (www.tuencyclopedie.nl).

At first glance, the range of developments in which Alexander Horowitz has been involved is surprisingly wide spread; from radio buttons, to a complete dry construction building system, to machines for agricultural tillage. What these developments have in common is their connection to mechanical engineering and advanced industrial production technics. The resulting precision in concept and realization can also be found in POLYNORM's construction system.

In 1948, the efforts were to rebuild Europe after the Second World War. The aim of the company was to be able to meet the enormous demand for housing with industrially manufactured residential buildings despite the scarcity of raw materials and the shortage of skilled workers. At the beginning, the project was actively supported by the Dutch Minister for Reconstruction as part of the Marshal Plan (Bouwmeester, Timmermans, Post 2006, chapter 1). In the early 1950s, a housing estate with 212 houses was built in Eindhoven using the POLYNORM construction system for the employees of the Philipps company. One of the last houses to be demolished on this estate was studied by the TU Eindhoven before being dismantled and temporarily rebuilt for an exhibition (Bouwmeester, Timmermans, Post 2006). However, the expected production volumes for the economically successful production in Holland could not be achieved due to the discontinuation of Marshal Plan subsidies and the company had to expand abroad with an extended construction system including industrial halls. In the survey "POLYNORM. Innovations and insights from a building system of the Dutch reconstruction" (Ogunsola. 2023), the development of the company at the beginning of its history is traced.

From its foundation in 1948 until the second half of the 1950s, NV POLYNORM constantly developed its industrially produced system for buildings and adapted it to new types of use. This can be concluded from the documentation of realized buildings, various advertisements and a considerable series of patents. The survey "POLY-NORMEN, wie sich aus Normen Poteziale eröffnen" (Jungo. 2023) has linked several construction techniques developed and patented by NV POLYNORM with the investigated hall of Fribourg.

1.2. The growing of a building system

The modular system started with a comprehensive and very ambitious construction system developed for residential buildings. The program included an industrially manufactured load-bearing structure made of folded metal sheet and a modular façade made of fiber cement panels. The multi-layer envelope of the building, including an insulating layer and a vapor barrier, was very progressive at that time. The range included floor slabs and partition walls for the interior finishing, as well as windows and doors to match the system. This phase of the POLYNORM system was examined in detail at the TU Eindhoven and documented with an analytical de- and re-assembly (Bouwmeester, Timmermans, Post 2006). (Fig. 2)

Figure 2. POLYNORM building site, Eindhoven, 1951 (Philips Company Archive).

In the early 1950s, industrial halls were built in Holland with a truss girder developed by POLYNORM. There is a patent for this type of building developed by Horowitz and Koekebakker in 1948 (Jungo. 2023. 8). (Fig. 3)

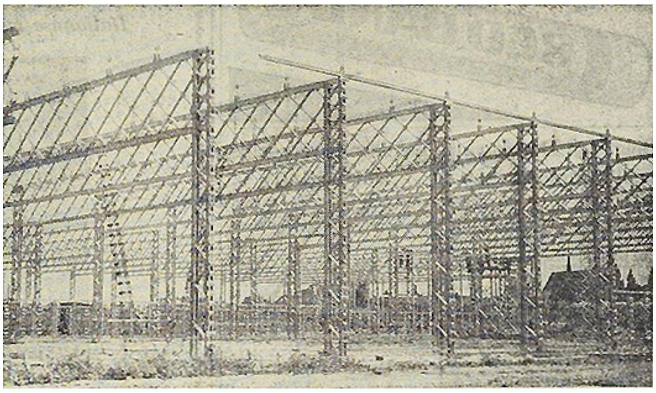

Figure 3. First factory construction by POLYNORM of Bunschoten (Dagblad voor Amersfoort 11.08 1951)

In 1952-53 the structural elements were standardized and NV POLYNORM registered several patents for a modular system to build industrial halls. The system was based on a newly developed truss girder with a double-shell for every chord and web elements. The separated shells could be piled into each other to save space during transportation from the production hall to the construction site. The design corresponds to the hall construction system later named as type-72. (Fig. 4)

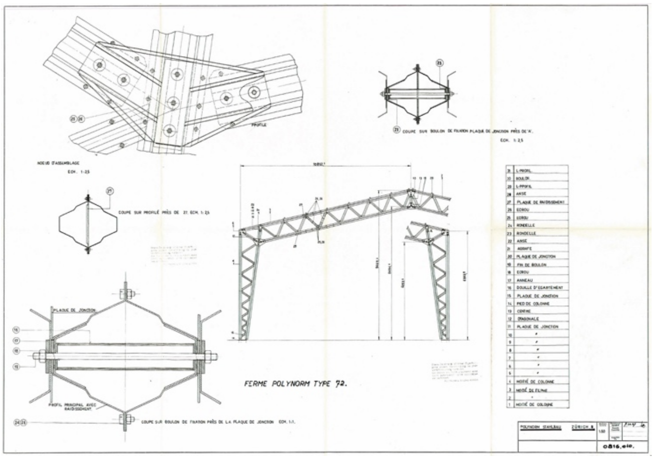

Figure 4. POLYNORM Zürich, Detailplan Fachwerkträger Typ-72, 1957. (Archives Ville de Fribourg).

Even though the resulting variants of the construction system are very different in terms of their area of application, several similarities can be identified.

The main system components are based on the advanced industrial processing of steel sheet. The techniques used range from cutting and folding, to stamping and pressing. These processes involve cold-working and deformation of steel (Jungo. 2023. Chapter 2.2.2 and 2.4.3). Individual welded joints are probably only provided in factory during prefabrication. During assembly, the connections are usually screwed, hooked or clipped. The concentration on one main type of material and its processing method probably has not only a business background in terms of the utilization of the acquired machines and the available workforce, but also in terms of the experience gained and the development of construction methods by the engineers. Another common characteristic in the further development of the system is the pronounced material efficiency of lightweight construction. Considerations for space-saving transportation and simple assembly as a dry construction with a minimum of skilled workers are further unifying characteristics of the different POLYNORM system variants.

1.3. The evolution of details in construction

A systematic analysis of isolated components and their further evolution in the history of POLYNORM can reveal the permanent growing of the modular system. This can be observed in the development of the clip for fastening metal sheet lamellas for the facade and roofing. (Fig. 5)

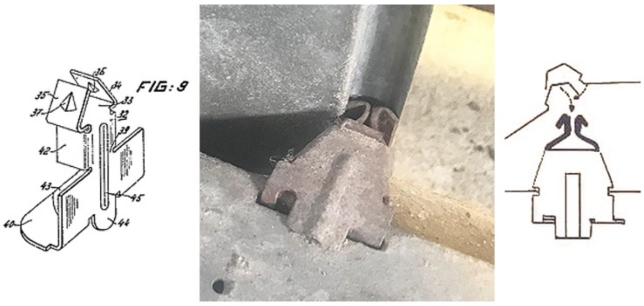

Figure 5. Clip for cladding: Patent FR1079026A, published: 25.11.1954 (Jungo). Photo of clip in Fribourg, 2022 (Transform). Clip detail, 1958 (Archives Ville de Fribourg)

Another example of constant evolution is the assembly of double-shell hollow profiles for a linear force transmission by means of a folding and pressing technique, which was developed in a relatively short period as shown in the following dated documents. (Fig. 6)

Figure 6. Truss assembly: Patent: R1056719A, published: 02.03.1954 (Jungo). Photo of hall in Fribourg, 2022 (Transform). Patent: FR1078020A, published: 15.11.1954 (Jungo).

2. The POLYNORM modular truss structure for industrial halls

The first POLYNORM hall that was built in Bunschoten and burnt down in 1952 was realized with a truss with crossed webs. The system for industrial hall was then developed into a trussed frame called typ-72. The structural system enables directional, column-free halls with a graduated length in a regular grid of 6.10 m (Fribourg 4.27 m). The span of the hall can be selected between three widths of 15, 22 and a maximum of 30 m (Fribourg 22 m).

As the examples built in Châteauroux (F) and Bergeyk (NL) show, a multi-span arrangement with a doubled load-bearing axis and a shared roof drainage is as well possible. The specified ridge height is not mentioned in the advertisements. (Fig. 7) However, the geometry of the main girders and the data sheet for the hall of Fribourg result in a fixe ridge height of 9.47 m and a free height under the structure of 6.25 to 8.50 m. Depending on the height of the base, the real room heights can also be more (Fribourg +30 cm).

Several advertisements for prefabricated hall buildings by POLYNORM Stahlbau Zürich appeared in the Schweizer Bauzeitung in 1957 and 1958 (Schweizerische Bauzeitung. 1957 and 1958). The structures described and illustrated correspond to the warehouse of Fribourg. (Fig. 7)

Figure 7. Advertisement POLYNORM-Stahlbau-Zürich (Schweizerische Bauzeitung, Heft 5 1957).

The building envelope and the fenestration can be easily adapted to the needs of the client according to the advertisements and the different known examples. This allows for the widest possible range of applications. Depending on the openings, fenestration and interior cladding, simple warehouses, various production facilities and even exhibition or sports halls are conceivable (Schweizer Bauzeitung, Heft 5 1957).

Several original POLYNORM hall structures could be identified in Holland, France and Switzerland.

A very large logistics center for NATO and the US Air Force was built at Châteauroux airport (Indre, F) in 1953. Interconnected warehouses covering more than 300’000 m2 of floor area were built with the POLYNORM type-72 system. (Fig. 8) Today, the buildings are used for civil purposes and preserve the original truss structure.

In Bergeyk (NL), a new production facility was built for the De Ploeg weaving mill in 1957. The project for the shed halls realized in in-situ concrete was designed by the Dutch architect Gerrit Rietveld. Three warehouses with the POLYNORM system came to stand on the company site (Das Werk. 1963, Heft 3). The original halls are probably still standing today, but with a renovated building envelope according to satellite photos.

Figure 8. POLYNORM hall built by US Air Force, 1953, Châteauroux-La Martinerie, F (www.france-air-nato.net).

As known, in Switzerland two POLYNORM halls have been built by POLYNORM Stahlbau Zürich, an independent Swiss company without its own production facilities. In 1957 the factory hall of the IVF Verbandstoff-Fabrik in Neuhausen am Rheinfall (CH), was built, as illustrated by advertisements (SBZ 1957-47 and 1958-6). Unfortunately, without systematic documentation, the structure was demolished in 2019, as confirmed by the owner.

The POLYNORM hall of Fribourg was realized in 1958 as a warehouse close to the urban center.

3. The case study POLYNORM hall in Fribourg

In summer 2022, a complete POLYNORM hall structure, including the associated building envelope, was dismantled in Fribourg as part of a research project by the TRANSFORM institute, HEIA-Fribourg. The elements were identified as original POLYNORM components based on their specific characteristics and the archived building application plans.

The industrial hall was part of a production facility for cardboard packaging for the company CAFAG/PAPRO SA on Rue de l'Industrie in Fribourg, Switzerland.

3.1. Description of the building

The hall construction is based on the POLYNORM truss girder type-72 made of folded steel sheet. The main hall spans a column-free area of 21.38 m in width and 31.80 m in the longitudinal direction with seven truss frames; the ridge height is 9.85 m. The load-bearing lightweight structure is anchored on a 30 cm high strip foundation made of in-situ concrete. Adjustment to the existing topography was made with embankments and small retaining walls. The hall structure thus came to rest on a uniform horizontal level.

The outer cladding of the four main facades consists of individual 15 cm wide, galvanized metal sheet lamellas that are fixed directly to the load-bearing system with a metal sheet clip that is also part of the POLYNORM system. The inner cladding of the facade surfaces is made of 2.5 cm thick, natural-colored wood fiber boards, which are clamped precisely between the supporting structure. The roofing consists of corrugated fiber cement panels attached to the purlins with brackets. The inner cladding of the roof surface consists of 2 cm thick, white polystyrene insulation boards nailed from below to a wooden grid, which is clearly not part of the POLYNORM system.

A series of 2- and 3-light windows are installed in all four of the main facades at a uniform height of 5.70 meters. These metal framed windows with single glazing fit precisely into the POLYNORM construction system. Four solid steel sheet doors are installed on three sides of the building. It can be assumed that the windows and doors were also manufactured by POLYNORM and are based on earlier components for the residential buildings.

The entrances to the main hall are covered on both gable ends. The attached roof construction of welded trusses rests on the inner side directly on the POLYNORM structure and on the outer side on concrete pillars, which are adapted to the terrain.

Figure 9. Dismantling POLYNORM hall in Fribourg, 14.09.2022 (Transform).

3.2. The building history

The building application for the warehouse in Fribourg was submitted to the city of Fribourg on 26.9/3.10.1957. The archived plans at a scale of 1:50 are dated March 6, 1958 and signed by the company CAFAG / PAPRO SA Fribourg. POLYNORM Stahlbau Zürich is noted on the drawing of the ground floor as construction company for the steel structure. The archived type plans for the truss girder type 72, dated 7.10.1957, and the detailed sketch of the slatted façade made of folded sheet steel also match this.

The realized main dimensions of the finished building correspond well with the building application plans. However, it should be noted that the number of structural axes was increased by three, from 4 to 7 plus two gable axes each. Fenestration and access doors were not executed according with the building application plans.

The first measurements were taken by HEIA-Fribourg in 2013, when the hall was still used as a warehouse and equipped with free-standing high-bay racking. In summer 2022, the entire POLYNORM structure, including the facade cladding, as well as the windows and doors, was professionally dismantled and documented. The analytical disassembly has provided valuable insights into engineering and assembly of the hall. The hall is currently in storage, dismantled into more than 2’000 individual parts. The entire structure is currently being examined and prepared for reconstruction. The total weight of the dismantled structure was found to be under 8 tons; which is about five times less than a comparable steel construction made today. (Fig. 9)

3.3. The building structure

The basic element of the structure is a truss frame with a specified span of 15, 22 or 30 m. The frames are connected to each other with girts in the facade and purlins in the roof area.

The horizontal forces perpendicular to the ridge are taken directly by the truss frames and transferred to the foundations. Horizontal bracing in the longitudinal direction is ensured by a horizontal truss frame on each of the two gable walls. (Fig. 10)

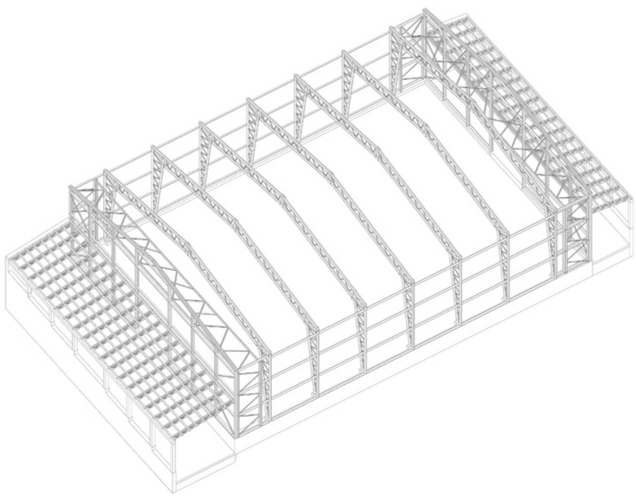

Figure 10. Measurement and isometric drawing of POLYNORM hall Fribourg. 2013 (HEIA-FR by students Fleury and Oliveira).

The girts and purlins serve both as a longitudinal bracing and as a substructure for fastening the building envelope and roofing. Several vertical bars are arranged between the structural axes, which stabilize the girts and purlins and allow the installation of windows and interior cladding.

The entire load of the structure is transferred to the foundations via the external chord of the truss frame column. The connection is ensured by a steel anchor plate and a single bolt. The connection is designed as an articulation and only transfers vertical load and tensile forces.

3.4. The truss girder

The centerpiece and the most striking component are the truss girders, which are made of folded sheet steel with a material thickness of only 1.75 mm. The girder consists of a pair of upper and lower chord connected by diagonal webs. In the area of the vertical column, the pair of chords converge downwards and are connected with the same type of diagonal webs.

All truss elements are assembled of two half shells. The longitudinal edges of the shells are bent outwards and are only screwed together during assembly on-site. This creates a hexagonal hollow body with two reinforced ribs. These ribs also serve as a connecting axis for attaching webs and other components of the system.

The deformation at the ending of the webs double shells to one flat level, allows the concentrated application of forces to the joint of the chords. The deformation of the shells takes place without loss of material and gives a visual impression of a continuous force progression. This double-shell profile and the pressed connection were patented by POLYNORM in 1953 (European Patent Office. FR107820A).

The entire truss frame consists of four major components, which are connected with additional steel parts and bolts at their junctions.

A plausible production, transportation and assembly process can be reconstructed based on the experience gained during the dismantling of 2022 and the survey by Jungo (Jungo. 2023. Chapter 2.4.2). The half shells of the truss elements are made on measure at the production site in Holland. Each truss girder is assembled as a half shell and fixed with a welded connection of the half webs to the half chords. For transportation to the building site, the half-shell truss girders and truss columns are piled into each other to save space (European Patent Office. FR107820A). At the construction site, the truss girders are assembled on the ground with the additional connecting pieces to form the complete truss frame. Thanks to their minimal weight, the finished frames can be raised and connected with the horizontal girts to the complete final building structure.

3.5. Substructure for the building envelope

The girts, made of folded metal sheet, are attached directly to a plier-like connecting interface to the trusses. They serve both as connecting beams for the main structure and as a substructure for the facade cladding and roofing.

Systematic perforation of the substructure allows individual clips for the facade to be attached, window frames to be fixed and internal cladding to be clamped in place. The individual connecting elements will be discussed in a separate section.

3.6. The building envelope to clip on

POLYNORM developed an external cladding made of galvanized steel sheet for the facade and the roofing, and had it patented back in 1953. A multi-edged metal sheet lamella is clipped under tension into punctual holders produced of metal sheet as well. The small overlap prevents water penetration.

During dismantling, it was discovered that the vertical slats in the gutter area were additionally hooked in. This highlights an easy and fast installation by hand, favored by the little weight of the lamellas. The hook may also prevent the slats from slipping due to dilatation movements.

The vertical grid of the slats is continued in front of the structural axis of the truss frames. A special clip is fixed at the joint of the frame axis.

The corners of the building are formed with a modified L-shaped slat and fixed with screws. This shows that a very pragmatic approach was taken to the limits of the modular system.

After disassembly, some of the slats were found to be severely deformed and must be straightened before reassembly. Using a mock-up with original slats from above the windows, it was possible to investigate how the fold-and-clip connection works in detail. With these findings, a possible reassembly of the POLYNORM hall can now be prepared.

The roofing of the hall was made, right from the beginning, of corrugated fiber cement panels, which were attached to the purlins with screw brackets. The roofing, which contained asbestos, had to be removed.

3.7. Bolting, clipping and clamping

POLYNORM has used various techniques to connect individual components on site. Some of these have been specially developed, patented and improved over the years. All selected techniques allow assembly in dry construction and without special tools. There is no need for gluing, casting or welding on site. This also allows easy disassembly or adjustment at any time. The connecting parts are industrially manufactured and are attached directly to the POLYNORM structure in pre-stamped openings. The clips and clamps are equally made of steel sheet and can be manufactured using the punching and forming processes already used at the POLYNORM factory.

For bolted connections only metric hexagon head bolts with washers and nuts are used. The holes steel sheet components are pre-stamped at regular intervals.

The system of clipping into a punctual connecting element allows the building envelope to be installed from the exterior side only. The sheet metal slats of the facade, some of which are very long, are subject to strong dilatation when the ambient temperature changes. The clipped connection allows the resulting dilatation movements. The clip is inserted directly into the slot cutouts provided in the substructure and snapped into place. The multi-edged sheet metal of the slat is pressed between two adjacent clips, whereby the inner edge of the metal sheet fold clamps into the barb of the clip. The bent shape of the metal sheet lamella keeps the connection permanently under tension. (Fig. 11)

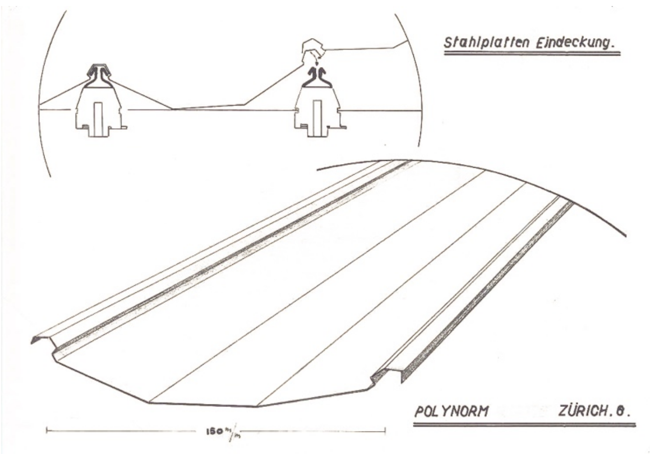

Figure 11. Clip for cladding «Stahlplatten Eindeckung», 1957, POLYNORM Zürich (Archives Ville de Fribourg).

The clamp mounting on the other hand, is used to attach precisely cut to size panels between the structure. As the connection has to adapt to different materials and material thicknesses depending on the execution, different technical solutions were developed. An early patent from 1951 shows a linear clamping strip with a cover profile. This variant for mounting interior cladding was used in the residential buildings in Eindhoven. (Fig. 12) In the POLYNORM hall of Fribourg, 2.5 cm wood fiber boards were used for the interior cladding of the facade. These panels were presumably manufactured in the Pavatex factory located just a few hundred meters from the construction site. The fitted panels are clamped directly in between the beams of the structure using a pair of clamps inserted into pre-cut slots and snaped into place automatically. The pairs of clamps are located at a distance of approximately 60 cm on all four sides of the fiberboard. Since there are no pre-punched slots in the double-shell chords, special clamps made of folded metal sheet are used near truss frames.(Figure 12)

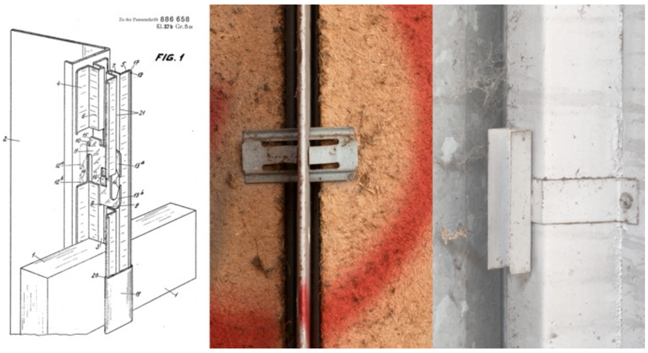

Figure 12. Clamp to fix panels: Patent: DE886658C, published: 17.08.1953 (Jungo). Photo standard clamp and special clamp, Fribourg 2022 (Transform).

4. Various observations on the POLYNORM system

The ongoing research on the POLYNORM system has led to new questions, both in terms of historical research and in terms of analytical deconstruction. Since work on the Fribourg POLYNORM structure is still ongoing, the following results are preliminary.

The system developed by POLYNORM in the 1950s, as well for housing and industrial buildings, is a modular system open to significant modifications. As a system, POLYNORM is not limited to a specific type of building or even to a pre-determined floor plan. Rather, it is a collection of constructive solutions to various issues. An example can be seen in the adjustment of the axial distances of the Fribourg warehouse structure; the original 5 axes with the standard spacing of 6.10 m, were modified to 8 axes with a reduced spacing of 4.27 m. (Section 3.2) Another example of the simple pragmatic evolution of components is the evolution of the clamping system for interior cladding. The same mounting technology for pinching a panel like material, was modified from clamping with a linear bar in residential buildings, to a simple punctual pinching with two clamps for the industrial buildings. (Fig. 16-18)

In the course of POLYNORM's history, the individual metal sheet components have been developed for the same type of construction detail or assembly technique. The industrial processing of steel sheet for the various system components is based on "cold methods" processing (Bouwmeester, Timmermans, Post 2006. 36). The concentration on one type of processing technology is described in detail in the study "POLY-NORMEN, wie sich aus Normen Poteziale eröffnen" (Jungo. 2023. Chapter 2.2.2). The relative ease of working with thin metal sheet is probably an advantage for simple and low threshold adaptations in industrial processing and adaptations on site.

The long-term durability of the conceptual design and materials used in the known POLYNORM warehouses seems to be good after almost 70 years of use. The warehouses in Châteauroux (F) and Bergeyk (NL) are still in use, according to Internet verification. Only the roofs appear to have been replaced.

After more than 60 years of use, the case study hall in Fribourg was dismantled and examined in 2022. The interior space, interior cladding, and truss structure were dry and therefore well preserved. Only a few minor exceptions have been noted due to lack of maintenance in recent years. All bolted connections were easy to loosen and showed only little corrosion. A single severe deformation was found in one double-shell chord of the gable. However, the load bearing capacity of the building structure was not questioned, suggesting a great resilience of the lightweight structure.

In order to prepare the Fribourg POLYNORM hall for a new life cycle, a number of studies have to be carried out. Central to the reconstruction of the structure is the verification of the static safety. The most exact measurements, the assembly details and the properties of the materials are to be incorporated into a structural model calculation. At the level of individual components, some of them need to be straightened, repaired, or even replaced. In order to provide the components for the planned reconstruction, it is important to have a detailed knowledge of the original production technology and the machines used, based on historical research.

Conclusion

The survey into the history of POLYNORM hall constructions has revealed that the influence of the mechanical engineer Alexandre Horowitz was formative for a number of construction details. The use of high-quality, thin steel sheet as a building material for the structure and the building envelope has led to new, innovative construction details. Horowitz used his well-founded knowledge of the processing and production technology of steel sheet components to develop a comprehensive modular system for industrial halls and residential buildings.

The development of individual components can be traced through several patents and original drawings. Initial construction details for realized prototypes, such as the dwellings in Amersfort or the first factory building in Bunschoten, soon led to further developed and optimized components. The industrial production of half-shell trusses and the building envelope took place at the POLYNORM factory in Holland. Compared to traditional construction methods, transportation and assembly of the relatively light and stackable components were made easy. The extent to which out-of-system construction details or materials may have been possible is still under investigation. The hall of Fribourg deviates from the standard construction with its smaller grid size and its specific interior cladding.

The analytical dismantling of the Fribourg hall provided not only detailed information about the construction, but also insights into the assembly and disassembly processes. It is worth mentioning the advantages of a very light dry construction method that can be carried out without heavy equipment and with simple means. The fact that all components could be easily dismantled in their original form after 65 years of use, indicates a durable, well-designed construction. These findings and the knowledge acquired about the industrial production of POLYNORM components allow also conclusions to be drawn for material-efficient and durable constructions in terms of circular economy.

Acknowledgements

This study is part of the POLYNORM research project founded by the Smart Living Lab (SLL), together with Nouvelle Politique Régionale NPR, Plan Climat Fribourg and partners of the private economy.

The chair of Construction Heritage and Preservation, ETH Zurich, made significant contributions with student investigations into the construction of NV POLYNORM.

For key inputs and valubales feedback Robert Walker, Raffael Baur and Prof. emeritus Arthur Rüegg are to be warmly thanked.

Bibliography

Bouwmeester, Henk and Timmermans, Guus and Post, Jouke. 2006. Woningen uit de fabriek. Technische Universiteit Eindhoven.

Claessens-Vallet, Camille. 2022. Structure à réemployer cherche maître d'ouvrage pour relation durable. Tracés, 7.11.2022.

Das Werk. 1963, Heft 3. Factory N.V. Weverij De Ploeg, in Bergeyk, Holland. https://www.e-periodica.ch/digbib/view?pid=wbw-002:1963:50::2053#316

Eads, Edwin M. 1955. USAF-NATO Construction in France. The Military Engineer, Vol. 47, No 318, 1955. https://www.jstor.org/stable/44570595

Jungo, Renée Lou. 2023. Vertiefungsarbeit: POLY-NORMEN, wie sich aus Normen Poteziale eröffnen. Chair of Construction and Heritage Conservation, ETH Zurich.

Ogunsola, Oluwasegun. 2023. Vertiefungsarbeit: POLYNORM, Innovationen und Erkenntnisse aus einem Bausystem des niederländischen Wiederaufbaus. Chair of Construction and Heritage Conservation, ETH Zurich.

Schweizerische Bauzeitung. 1957, Heft 5 und 47.

Schweizerische Bauzeitung. 1958, Heft 6.

Vanbutsele, Séréna. 2022. NPR rapport final: Étude de déconstruction d'une halle industrielle pour un réemploi des composants -structures et façades- dans une démarche d'économie circulaire pour un cas concret.

Van der Woord, Jan. 1996. Verslag Bedrijfsbezoek Polynorm Bouwprodukten: Een schuifdeur neemt ruimte in. https://booosting.nl/news/show/id/749

Online sources

European Patent Office. NV POLYNORM: *Barre profilée à section en forme de canal* FR1078020A

https://www.tuencyclopedie.nl/index.php?title=Horowitz_A.

https://www.tudelft.nl/en/about-tu-delft/alumni/inspiring-alumni/historical-alumni/alexandre-horowitz

https://nl.wikipedia.org/wiki/Alexandre_Horowitz