Fire Protection of Historic Buildings through Gypsum Products

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Summary

Gypsum and gypsum based products are particularly suitable for fire protection because of their chemical nature. Gypsum is calcium sulfate dihydrate $CaSO_4.2H_2O$. By weight, each gypsum molecule contains 21% water. At high temperatures, as in the case of fire, this combined water is released and evaporates. This process requires energy which significantly retards the transmission of heat.

According to the European classification system, gypsum products will be classified in classes A1 (glass mat reinforced gypsum boards, gypsum plasters, gypsum blocks) or A2 (gypsum plasterboard) in the future.

Gypsum boards are widely applied for fire protection due to their excellent fire behaviour and other beneficial properties both for new buildings as well as for renovations. Their application in historic buildings is therefore obvious. This is demonstrated by case studies on some cultural monuments in Germany and Austria. In this context, the often conflicting regulations on fire safety and preservation of cultural heritage are discussed here.

Key words: gypsum, gypsum boards, gypsum plasterboard, fire safety, fire resistance, case studies, preservation of cultural monuments

1. Introduction

Gypsum is a traditional building material, well-known and well-proven since milleniums. Gypsum plaster and gypsum mortar were applied, e.g. in the Cheops pyramid, in the interior walls of Pompeii, and in the palace of Knossos. The word gypsum itself and the corresponding expressions in other European languages are derived from the ancient Greek word guyoV . There existed also a verb guyow which means "to plaster", "to coat with gypsum".

Over centuries, working with gypsum plaster remained the task of skilled craftsmen and artists, the latter particularly in the Baroque and Rokoko periods. The development of modern gypsum products and technologies began at the end of the 19^{th} century. Basic and applied research went hand in hand with those developments. The invention of gypsum plasterboard and the introduction of the corresponding drywall technology made a strong impact on the use of gypsum products in building construction. At present, the annual consumption of gypsum plasterboard in the United States, the biggest consumer, is approximately 10 m^2 per capita. In Europe there is gradient from about 5 m^2 in the Nordic countries down to less than 1 m^2 in southern countries.

2. General properties of gypsum products [1]

The wide application of gypsum based building products is attributed to a number of advantageous properties. The raw material is available world-wide. Rich gypsum deposits are found in many countries. Moreover, gypsums from technical processes, particularly the FGD gypsum from flue gas desulfurisation of coal fired power stations, have gained more and more importance. Gypsum products are economical. They promote a good room climate

Gypsum boards have distinct benefits:

- Low density in the range of 700 to 800 kg/m^3, therefore no static load problems
- Sophisticated technology in manufacture, application and job site logistics.
- Clean job site operation, very little waste.
- Non-combustibility and excellent performance in fire resistance.
- Suitable to receiving many types of surface decoration.
- Particularly suited for both new buildings and for rehabilitation purposes.

3. Behaviour of gypsum products in fire

Gypsum and gypsum based products are particularly suitable for fire protection because of their chemical nature. Gypsum is calcium sulfate dihydrate $CaSO_4.2H_2O$. By weight, each gypsum molecule contains 21% water. At high temperatures, as in the case of fire, this chemically combined or crystal water is released and evaporates. This process requires energy which significantly retards the transmission of heat.

The following chemical equations apply:

$$CaSO_4.2H_2O = CaSO_4.1/2H_2O + 3/2H_2O$$
$$CaSO_4.1/2H_2O = CaSO_4 + 1/2H_2O$$

Equation 1 takes place, in practice, at temperatures around 110°C, equation 2 above 160°C. The process is called calcination. When exposed to fire, the evaporating water keeps the unexposed surface cool for a certain time until the gypsum is completely calcined. Fig. 1 shows a typical time-temperature curve.

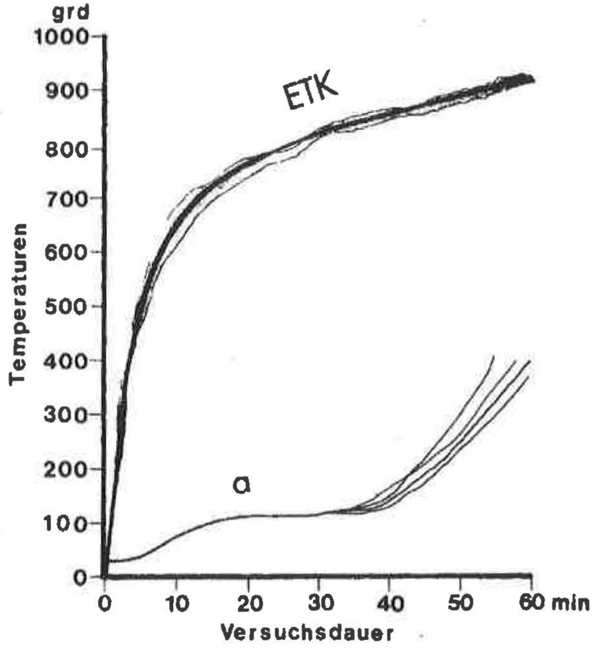

Figure 1: *Typical time-temperature curve from a fire resistance test of a steel stud partition lined with 15 mm gypsum plasterboard F*

Gypsum plasterboards type F have glass fibres and other additives in the gypsum core to improve the core cohesion at high temperatures so that the assembled systems keep their integrity for a longer period of time.

According to the Council Directive the future European classification system [2] will classify purely mineral gypsum products in class A1 (gypsum plasters, gypsum blocks) [3]. Special glass mat reinforced gypsum boards will be expected in class A1, and gypsum plasterboard to EN 520 will be very likely in class A2. Furthermore as far as the building codes in Germany and Austria are concerned, gypsum products remain non-combustible.

4. Legal requirements for fire safety and preservation of historic monuments in Germany and Austria

In both countries the legislation is a matter of the Federal states. However, there is much common sense and equal or similar regulations on fire safety issues. In Germany, there exists the MBO, the model building code which contains the general rules on building construction including fire safety [4]. The Federal states follow this given route, at least in the basic requirements. The general clause for all kinds of building construction is that they have to be installed, erected, modified and maintained in such a manner that public safety and order, in particular life and health, are not endangered. Derived from this general clause, the main objectives of fire protection are

- to avoid the generation of a fire
- to avoid the propagation of fire and smoke
- to safeguard the rescue of users and inmates of a building installation

and

- to enable effective fire-fighting actions

The model building code MBO distinguishes buildings according their height

- buildings of low height up to 7 m
- buildings of medium height between 7 and 22 m and
- high-rise buildings above 22 m for which special regulations are applied

As to the reaction to fire behaviour the building products are divided in non-combustible (A1 and A2, in Austria only A) and combustible building products whereas these are again subdivided into building products difficult to ignite (B1), normally ignitable (B2) and easily ignitable (B3) [5]. The essential classes of fire resistance of building components and structures according to the MBO are the classes F 30 and F 90. F 60 has some significance in Austria. In Germany the fire resistance class F 90 can only be assessed if all (F 90 A), or at least the essential components (F 90 AB), are non-combustible materials.

Requirements for building elements according to the MBO

	Height <=7 m	Height 7 – 22 m
Load bearing walls, pillars and columns	F 30 B	F 90 AB
Non-load bearing external walls	B 2	F 30 AB or NC
Separating walls, e.g. between dwellings	F 30 B	F 90 AB
Ceilings	F 30 B	F 90 AB
Load bearing components of obligatory stairs	F 30 B or NC	F 90 AB
Walls of obligatory staircases	F 90 AB	as firewalls

NC = non-combustible

The laws and directives on preservation of cultural monuments are related to objects which shall be preserved on historic, scientific, artistic, ethnologic or urban planning grounds. The aim is to preserve the monument in its original substance [6]. Modifications and replacement of items or components are only permitted if strong superseding reasons like static or fire safety demands require those alterations. Due to the fact that preserving actions require considerable financial resources, an effective preservation can often only be carried out if the cultural monument is utilised in an economic manner. This may also lead to a rededication of a historic building, e.g. an old mill is converted to an inn, a warehouse to a hotel, a monastery to a dwelling-house etc. etc.

Strong requirements on public safety supersede, in principle, the needs for the preservation of cultural monuments. Some regional directives permit a considerable alteration, even the demolition of historic buildings if higher ranked public interests require these actions. So the legal situation is often a source of conflicts. The competent public authorities are requested to search for a wise compromise between contrary demands on public safety and preservation of cultural heritage.

A conflicting situation may arise from buildings of medium height (7 to 22 m, see above) where separating building components or ceilings must have a fire resistance of 90 minutes and must consist of non-combustible materials, at least in the essential components, a requirement which timber frame constructions cannot fulfil. The solution would be a special permission for a F 90 B construction which is usually granted by special permission. The new draft MBO will allow this combination. In Austria, this procedure is the rule, nowadays.

5. Application of gypsum boards – some case studies

Bearing in mind that gypsum plasterboard is a relatively modern building product and, of course not "historic", how can severe demands in the directives for the preservation of cultural monuments permit the application of gypsum plasterboard? There is no doubt that the use of these kinds of products leads to an alteration of the original state, sometimes even to a significant change. However, the choice of gypsum plasterboard systems is a good option, in particular, when static and fire safety grounds play a predominant role. Gypsum plasterboard is a lightweight, versatile and flexible building product which is susceptible to receiving almost any kind of surface decoration so that the final performance could give the impression of the original substance. This will be demonstrated by some case studies.

5.1 The Reichstag, the German parliament in Berlin

No other building reflects modern German history better than the Reichstag, again the seat of the parliament of reunified Germany since autumn 1999. The restoration was performed under the direction of the famous architect Sir Norman Foster.

Gypsum plasterboards are well represented in the Reichstag. The suspended ceilings consist of perforated gypsum plasterboard which were coated by a finely textured acoustic plaster in order to reduce the resounding effects. Although acoustic matters are beyond the scope of this conference they are, nevertheless, worth being mentioned [7].

However, many fire resistant steel stud partitions of classes F 30 A and F 90 A lined with gypsum plasterboard type F have been installed. A particular construction is a three layer F 90 partition wall at the halls of the parliamentary groups lined with 3x12,5 mm gypsum plasterboard type F.

5.2 The German Dome in Berlin

The German Dome (Fig. 2) is located in the heart of Berlin at Gendarmenmarkt, the most beautiful square in Germany's capital. With its twin edifice, the French Dome, and the German Playhouse, it forms an outstanding and harmonic constructional arrangement. All buildings were destroyed during the 2nd World War. So it was a complete reconstruction [8]. At present, the building is being used as a museum.

The German Dome has two cupolas, the 10 m high cupola on top of the 60 m high tower with an inner diameter of 9 m, and the hall cupola with an entire area of 600 m². There was a fire in 1994, but the base construction remained intact on the whole.

Design and execution of the inner cupola construction was a challenge for the drywall construction with gypsum boards. It required a high level of professional skill. The base construction for the small cupola in the tower was mainly prefabricated and could be easily assembled and hung on the bearing ring (Fig.

Figure 2: General view of the German Dome

3). As a vapour barrier, aluminium foil was fitted between the base construction and the gypsum plasterboards. They were precut to trapezoidal shape. All cut ends were carefully bevelled, fixed and the joints treated with a special gypsum based joint compound. The next step was the assembling of the big cupola at the lower section of the tower consisting of mounting the base construction, fitting the vapour barrier, installing the plasterboards (Fig.4) and finally milling the shadow joint.(Fig. 5).

The construction work at the hall cupola was similar. The base construction (Fig. 6) was lined with two layers of plasterboard. Eventually, perforated metal panels have been fixed underneath.

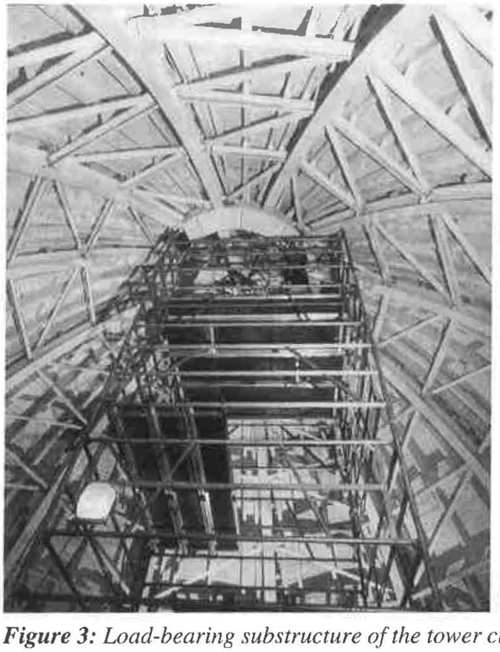

Figure 3: *Load-bearing substructure of the tower cupola*

Figure 4: *Attachment of gypsum plasterboard to the substructure*

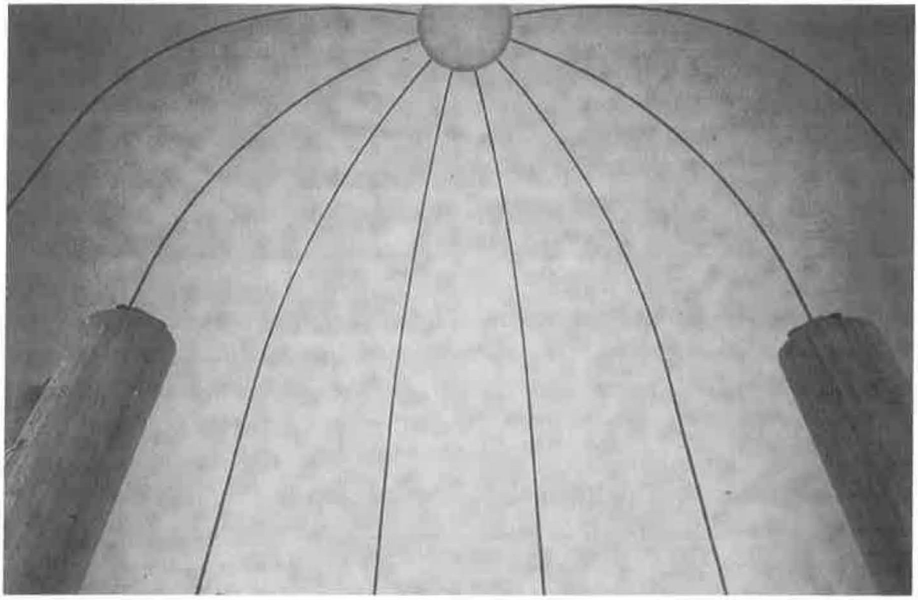

Figure 5: *Inner side of the finished cupola*

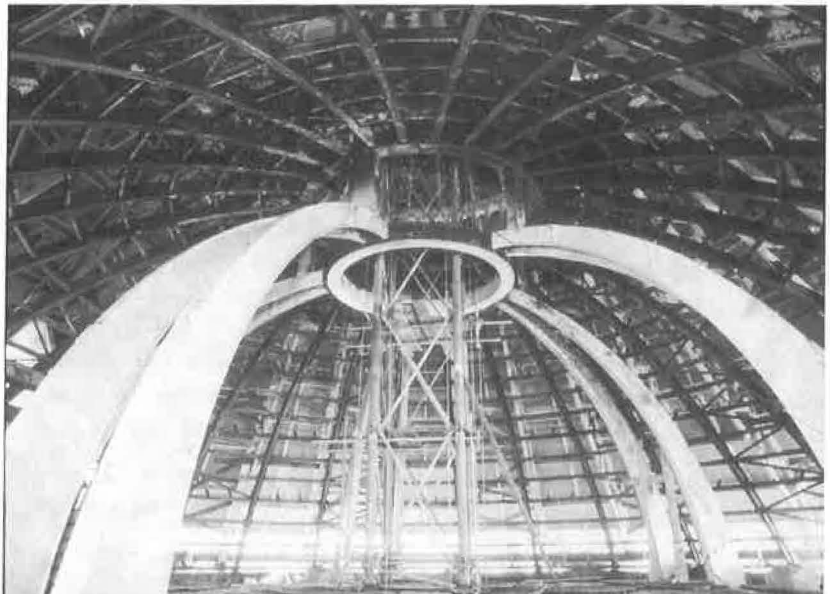

Figure 6: *Subconstruction of the hall cupola*

5.3 The Radeberg brewery in Dresden

The so-called Kaiserhof was an annex building to the Radeberg brewery. It was built in the late 19th century as the public bar with banqueting facilities. In the last few decades, the whole building decayed and the amply decorated historic hall was degraded to a gymnasium. After an extensive renovation the Kaiserhof reopened in December 1998 as a restaurant and hotel, an almost equal utilisation as previously.

From the fire safety aspect the most interesting feature is the really unique ceiling construction [9]. It is the combination of a fire resistant suspending ceiling (F 90-B) planked with 25 + 18 mm gypsum plasterboard type F and a second suspended ceiling fixed on the first one for decoration and additional sound absorption purposes. The suspension height of the first ceiling is 20 cm and of the second one further 60 cm. The cavity between the two suspended ceilings contains electric installations as well as ventilation and heating ducts (Fig.7).

The peculiarity of this construction is the deviation from the corresponding German standard DIN 4102-part 4 where it is clearly stated that fire resisting

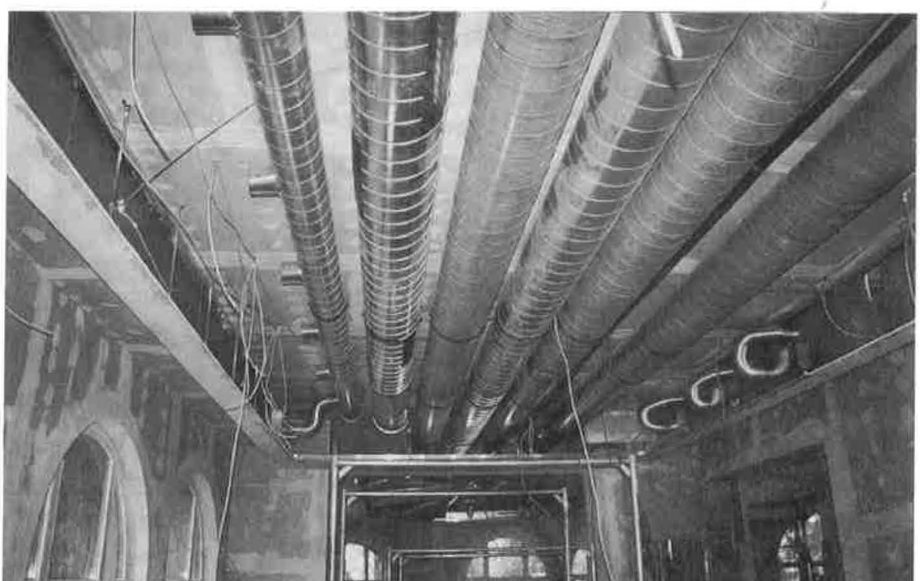

Figure 7: The Kaiserhof at the Radeberg brewery during renovation – the fire resisting (F 90) ceiling is installed as well as the heating and ventilation ducts

suspended ceilings must not carry load. So the second suspended ceiling had been fixed to the bare ceiling. This procedure was technically complicated and required much labour. A practical solution was found by a special expert assessment: The first fire resisting ceiling was suspended with a reinforced cross grid, and the hangers of the second ceiling were fixed by qualified steel screws on the bearing profiles of the first level.

5.4 The Technical Museum in Vienna

The Technical Museum (Fig. 8) is one of the earliest erected (1910-1913) iron concrete buildings in Vienna. An extensive rehabilitation was effected from 1994 to 1997 whose purpose was also to create additional space for the exhibition area, in total 3500 m² which is 30% of the previous area. This ambitious aim was mainly achieved by lifting the east and west cupolas and installing two-storey galleries underneath. Moreover, the loft was made useful by applying drywall systems with gypsum plasterboard (Fig. 9). The choice of these systems avoided a significant additional load on the foundations which was a critical issue in this project. All the requirements on sound attenuation, thermal insulation and fire protection were fulfilled. As to the fire protection, the building authorities required a fire resistance of F 60. So all the combined steel and timber framework in the loft was lined with two layers of 12,5 mm gypsum plasterboard type F [10].

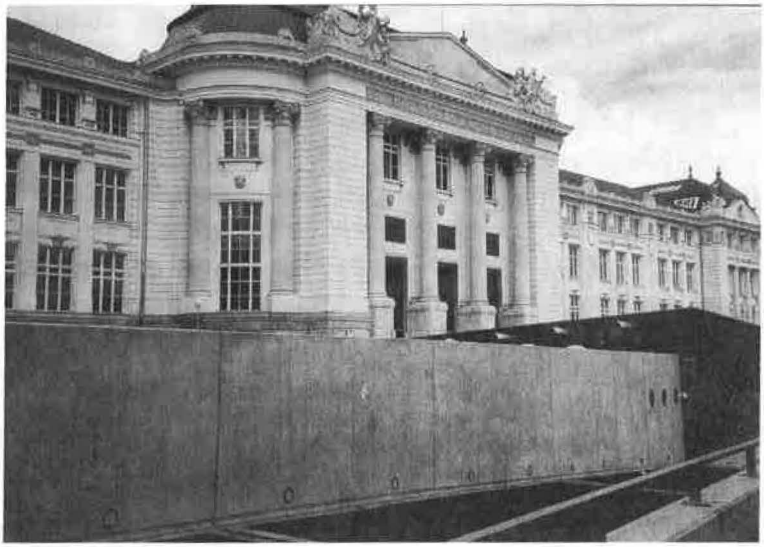

***Figure 8:** General view of the Technical Museum in Vienna*

Having highlighted some famous examples of cultural heritage let me also show you less spectacular and less known buildings which are, nevertheless, worth presenting due to interesting applications of gypsum building systems.

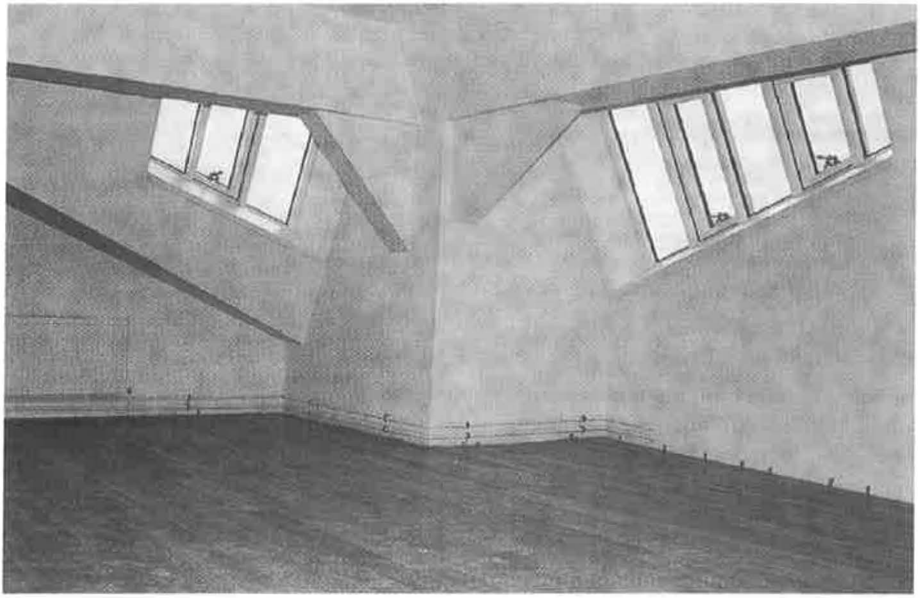

Figure 9: Additional useful room in the garret floor

5.5 The former Lünersee factory

This is a real industrial cultural monument (Fig. 10) which was built in the years 1836/37 as a cotton spinning-mill. It is located in the most western Austrian province of Vorarlberg near the Swiss border. In course of time the building was extended and weaving looms were added. It remained an industrial building. In the late sixties 200 employees and workers produced 5 million metres of textile fabrics per year. A few years later, the production became unprofitable and the factory had to close down. A rededication to a different utilisation was only a question of time.

During the recent restoration [11] the centre of the building was excavated to create an interior yard in order to bring more daylight into the building and to install two lifts. All the partition walls, also the curved ones, are metal stud partitions lined with gypsum plasterboard. At the ceilings (Fig. 11), the timber joists could be spared due to the application of special folding techniques (Fig. 12). This was not always easy because the difference in height went up to 34 cm.

The fire safety was achieved not only by the installed systems of non-combustible building products with required fire resistance, but also by the installation of sprinklers. In other words, this was an example of fire safety engineering.

Figure 10: *The former Lünersee factory after renovation*

Figure 11: *Renovating the former Lünersee factory – metal substructure for gypsum plasterboard ceiling*

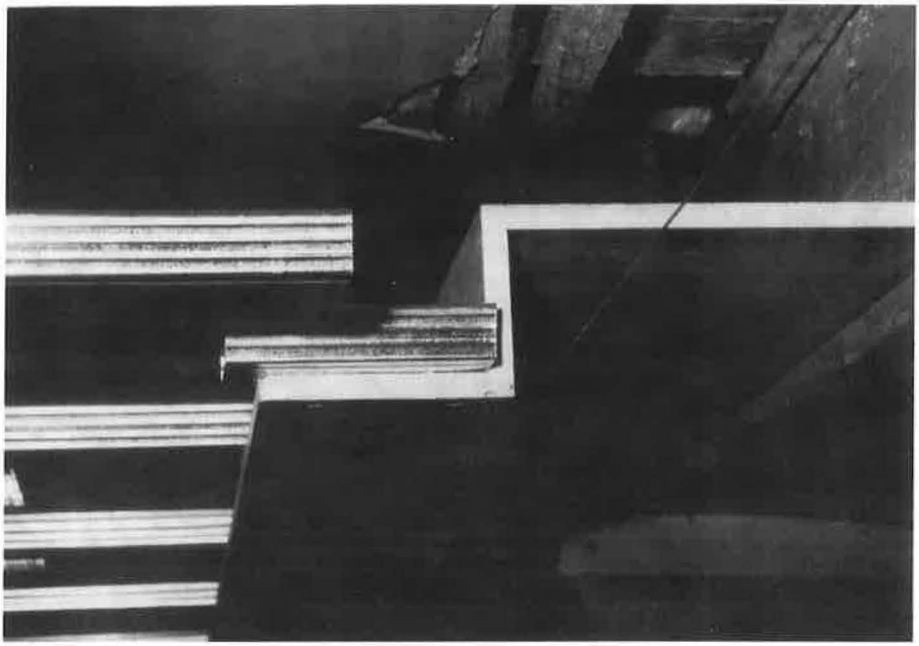

Figure 12: Application of folding techniques

5.6 Modification of an old school in a Franconian village

The former school at Obernbreit, a village in Franconia (Northern Bavaria) was built in the middle of the 19^{th} century. The building stood unused for many years. Eventually, the local authorities decided to transform it to a multi-media-house with offices, a bistro, a call centre, and a training centre for new media. The remodeling required a series of renovation actions. The ceiling of the ground floor above the basement had to be supported due to static reasons. Some rotten timber studs had to be replaced by steel columns and beams. The garret floor was completely remodeled in order to gain additional useful area.

Various systems with fire protection performance have been installed [12]:

- a dry screed consisting of two layers of gypsum fibre boards 2x12,5 mm, weight c. 30 kg/m², installed on a dry levelling layer to equalise different levels, having a fire resistance of F 90 (Fig. 13 and 14).
- Timber joist ceilings plus metal base construction of CD profiles lined

with 2x20 mm gypsum plasterboard, having a fire resistance of F 90 (Fig. 13 and 14).

- Steel beams encased with 2x20 mm gypsum boards lined with a glass fibre mat having a fire resistance of F 90 A.
- Garret floor cladding with 2x12,5 mm gypsum plasterboard type F fixed to CD steel studs which are, on their part, fixed to the existing rafters, fire resistance class F 90 B.

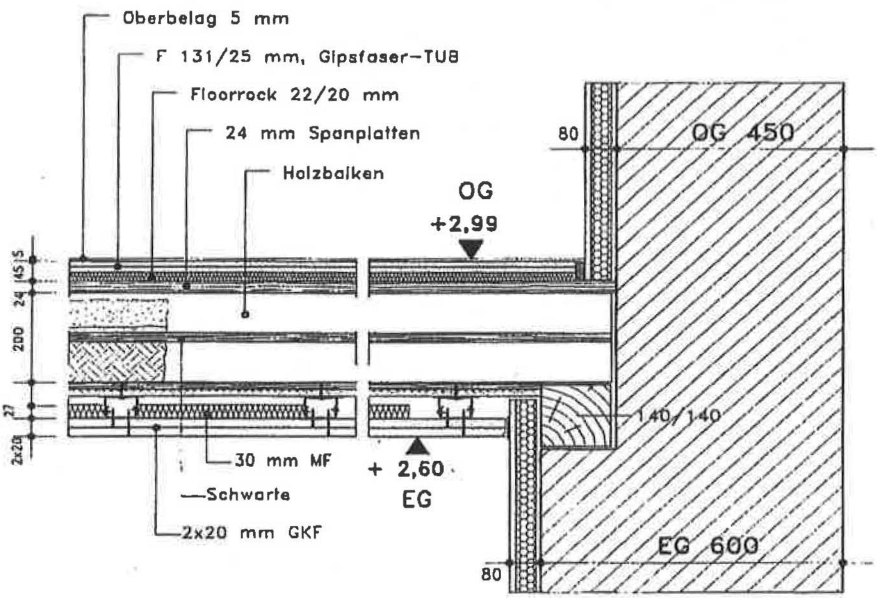

Figure 3, 14: Renovation of the former school at Obernbreit - sectional view of the ceiling above the ground floor at the south / east facade

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