A universal UHPC shell element for consideration of future building with precast elements

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1 Abstract

This article describes a technology of UHPC-precast elements (Ultra High Performance Concrete) from the idea to the concrete implementation and shows different possible applications. The development steps of the precast elements relate on the one hand the manufacturing up to the series product and on the other hand the joining technique of the elements. UHPC-prefabricated parts are joined using steel components. The bolted and/or tightened connections of the elements implement a later disassembly and thus a very sustainable use of UHPC- components in the sense of urban mining. The applications concern some examples of architectural objects where the first experiences with the production of UHPC-precast elements were made and which are shown in this article as an example. In the future UHPC-precast elements will play an important role in the field of civil engineering. A concrete prototype will be described and further developments will be shown. In civil engineering, in addition to the aspect of durability, the aesthetics, that results from the construction, play an essential role. It is therefore essential for the planning process of civil engineering structures to consider nature, ethics and aesthetics as equal value properties. The applications of UHPC-precast elements for building constructions are currently limited due to lower durability requirements. However ways are shown that allow meaningful applications. An economic application is given only when considering the overall life cycle. The aesthetics resulting from material-appropriate planning plays an essential role. In the future the consideration of good design will lead to creative construction products such as a universal shell element, which meets all the requirements of sustainable constructions.

Keywords: Planar UHPC-shell-elements; architectural objects; bridge-systems; flood-protection-walls; pretensioning; durability; sustainability; aesthetics.

2 General

Constructive precast elements made of Ultra High Performance Concrete (UHPC), as exemplified in the future ÖBV-Guideline for UHPC [1] for infrastructure construction, are characterized by a high resource efficiency when used in a material-appropriate manner. In the building material UHPC, as described in the German Assessment Report [2] as UHFB (German term), directional or non-directional steel elements are used, leading to a positive fracture behavior indication of components. The processing of the new building material as a prefabricated part with appropriate joining technology enables a later disassembly in the sense of urban mining.

The suitable material-orientated application of UHPC leads directly to shell or folded structures that take advantage of geometric stiffneses. This allows component thicknesses of 30 mm to 60 mm and thus a resource-saving use. The low porosity and the associated high resistance to external influences (climate, environment, mechanical and chemical) even at these low component thicknesses guarantees a high durability of the components and structures.

Vitruv's requirements for building construction in terms of carrying capacity (firmitas), utilization (utilitas) and beauty (venustas), already defined in antiquity, are more valid today than ever before and must be supplemented by the concept of sustainability due to the large number of construction products on the market. We civil engineers can plan and calculate sustainability through the use of durable building materials with high durability and resource efficiency.

3 Description of a universal shell element (USE)

The basic idea is a UHPC precast element with a steel fiber content between 2-3% by volume, which can be supplemented as required by directional steel elements (reinforcing steel, prestressing) and used as a universal shell element. It is the task of the planning engineer to make use of the spatial bearing effect.

3.1 Basic element

The basic element, which meets all the requirements of material-appropriate planning, is a carrying slab that has any shape in the ground view (Figure 1a). The carrying slab has an arbitrarily arranged folding edge, which span two planar surfaces at an angle α. The cross section of the carrying slab is plane-parallel and has a thickness of 30-50 mm. If the plate contains a prestressed strand, the minimum thickness is 50-60 mm (Figure 1b). If the prestressed cables cross each other in the plane a rib is formed. As prestressing method is the “post-bond tensioning” used.

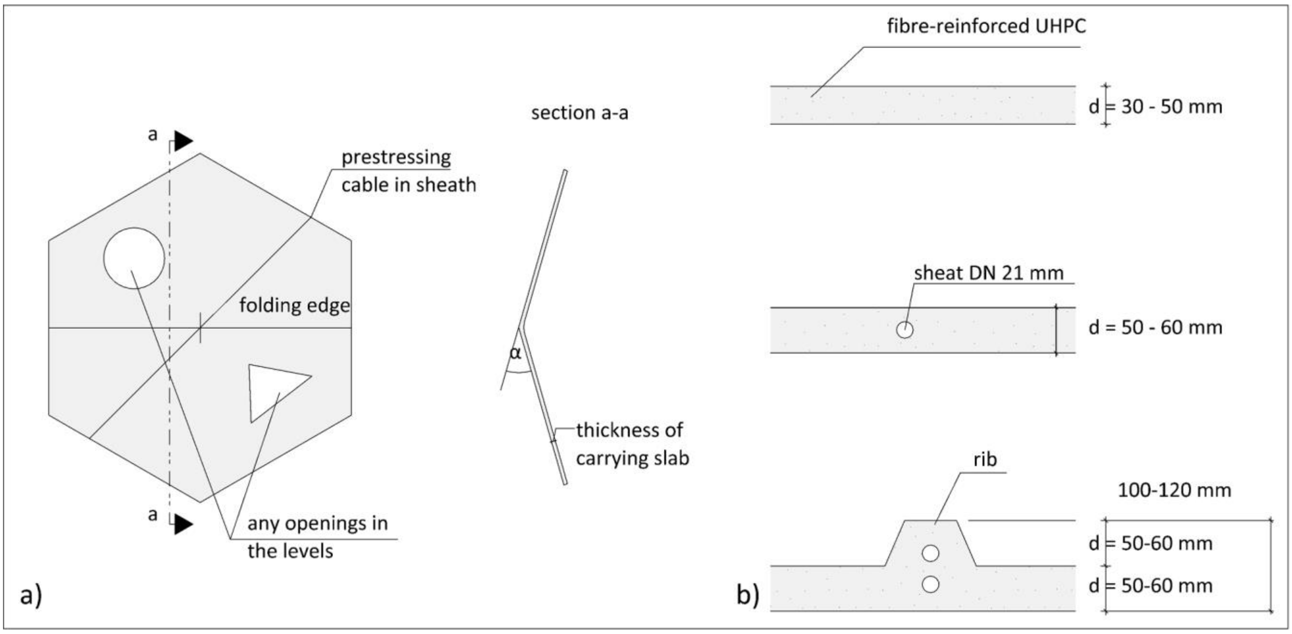

Figure 1. USE basic element a) Ground view and cross section b) Cross-section design

3.2 Manufacturing

The standard production of the carrying slab takes place in a specific formwork system. The lower part of the formwork system consists of a vertical fixed component and an upper folding wing part. Both shell parts are linearly connected via a steel hinge, so that the angle α is arbitrarily adjustable via spindle supports that carry the wing part. The formwork of the edges takes place by linear stopend panel or the formwork of the edges is formed by steel fittings. After applying all formwork on the planar precast element to the lower formwork table, the formwork is completed by adding the identical upper part of the formwork system and the building material UHPC is pumped into the airtight formwork.

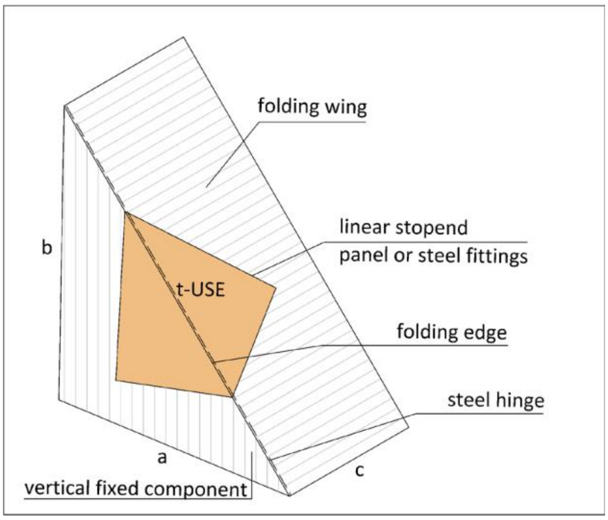

Figure 2. Construction formwork table for mass production

The UHPC is pumped into the formwork from below. A fillet r, especially from the lower formwork table, is required when using fiber mixtures, so that you can align equally in accordance with the flow direction (ascending).

The joining of the elements is always done with steel plug-in components to which steel can be connected in various ways.

It comes between two precast elements either the norm connection for use or, when connecting to an external component, the inflexible connection type for use. Reference is made to chapter 4 for examples of different joining options depending on the application.

4 Applications possibilities

The universal shell elements that can be mass-produced in the precast plant enable the construction of large-area constructions with high resource efficiency. The bolted and/or prestressed connections of the elements implement a later disassembly and thus a very sustainable application of UHPC components in the sense of urban mining.

With the production of this universal shell element a variety of design options in the civil engineering application of architectural elements, civil engineering structures through to civil protection buildings and building construction components are possible, which will be discussed below. The application is briefly described and the specificity of the designing in joining technology is discussed. USE elements are part of the UHPC-shell-construction [4].

4.1 Architectural objects

Among the first applications of the UHPC shell construction in working field are architectural elements. On the one hand, it is a flight of stairs slab over half a storey (Figure 3) with a slab thickness of 50 mm and on the other hand a sculpture (Figure 4) in the form of a cube with side lengths of 3 m and a plate thickness of 40 mm.

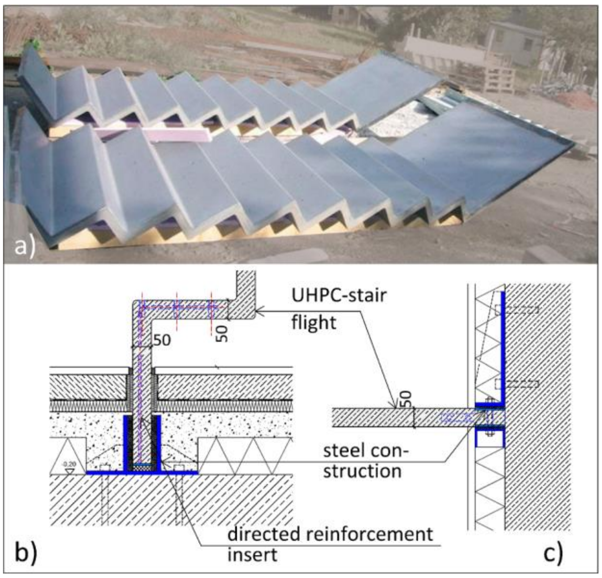

Figure 3. a) Stair flight as precast element
b) Detail connection stair flight - base plate
c) Detail connection landing - wall

The flight of stairs slab is manufactured in the factory in a free-standing steel formwork. The folding of the steps themselves give a high bending stiffness, so that with a slab thickness of only 50 mm, no appreciable oscillations in the use occur. All connections to the ceilings or walls are made by retrofitted steel components (Figure 3b and 3c). Directional reinforcing elements are used at the points of local stress peaks when the post-fracture resistance are exceeded.

The production of the plate elements with a thickness of 40 mm for the sculpture is also in the factory, but in a horizontal position with the disadvantage that the upper side surface forms a so-called "elephant skin". Accordingly, in any case free-standing formworks are to be preferred for future applications. Plug-in connections are used in the corner as joint elements (Figure 4b).

Figure 4. a) Sculpture b) Edge joint

4.2 Civil engineering structures

In civil engineering as well as in building constructions the UHPC-elements are used as a shell or folded construction. Constructing in space using geometric stiffness is of particular importance in engineering applications. The form-finding process in harmony with nature, ethics and aesthetics is part of the design work of the civil engineer.

Already in antiquity and later in the 19th century by Karl Friedrich von Gerock lies the meaning of the life of each man in the search for the truth, in the love of the beautiful and in the practice of the good. We can find the same for our building constructions expressed by the NEA-principle [5] (Figure 5) and apply them in the design of building constructions. This approach, which uses nature, ethics and aesthetics as the starting points of a design, is called the NEA-principle and manifests itself in good design. UHPC is a building material whose use, especially in civil engineering, derives primarily from construction and is characterized by particular resource efficiency.

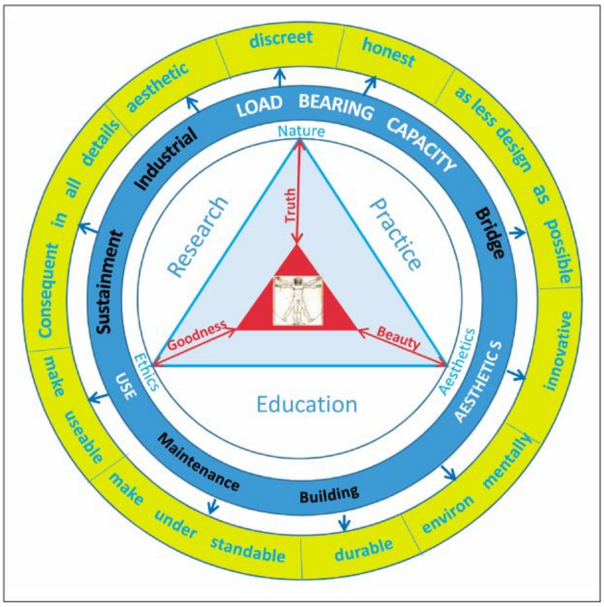

Figure 5. The NEA-Principle [5]

4.2.1 Bridges with UHPC-precast elements

The principle of open bridges can be implemented in an ideal way with the building material UHPC. The very durable building material UHPC offers the ideal conditions for system bridges made of prefabricated parts. These are integral bridge systems, without bearings and transitional structures, which can eliminate costly maintenance parts (e.g. Figure 6).

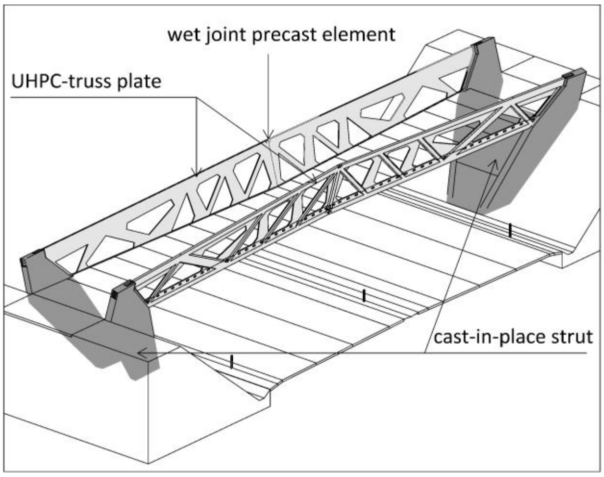

Figure 6. Bridge system type UHPC 325 [7]

With increasing span (from 25 m), due to the slender nature of the precast elements, spatial structures are taking advantage of the geometric stiffnesses (Figure 7b). The kink in the ground view in the symmetry axis with an angle of α1 = 2.7 ° leads to the positive effect of a spatial shell of the frame transom. This ensures the buckling stability of the upper flange of the UHPC-walls. The frame transom consists of two UHPC-wall elements per longitudinal side, which are subsequently joined together at the construction site by means of pre-stressing via wet joints (Figure 7 c), as exemplified in the Paulifurt bridge in Austria [6].

The frame leg is made by an in-situ concrete plate (d = 40 cm) with positive inclination of the frame leg, which is also used as a jacking block for load application of the preload forces in the assembled state.

A further development of the bridge type is shown in Figure 6. The UHPC-frame transom elements with the arrangement of the spatial buckling have been optimized in terms of the number of openings compared to the execution at the Paulifurt bridge. The UHPC-precast element [7] itself is adapted to a spatial truss plate.

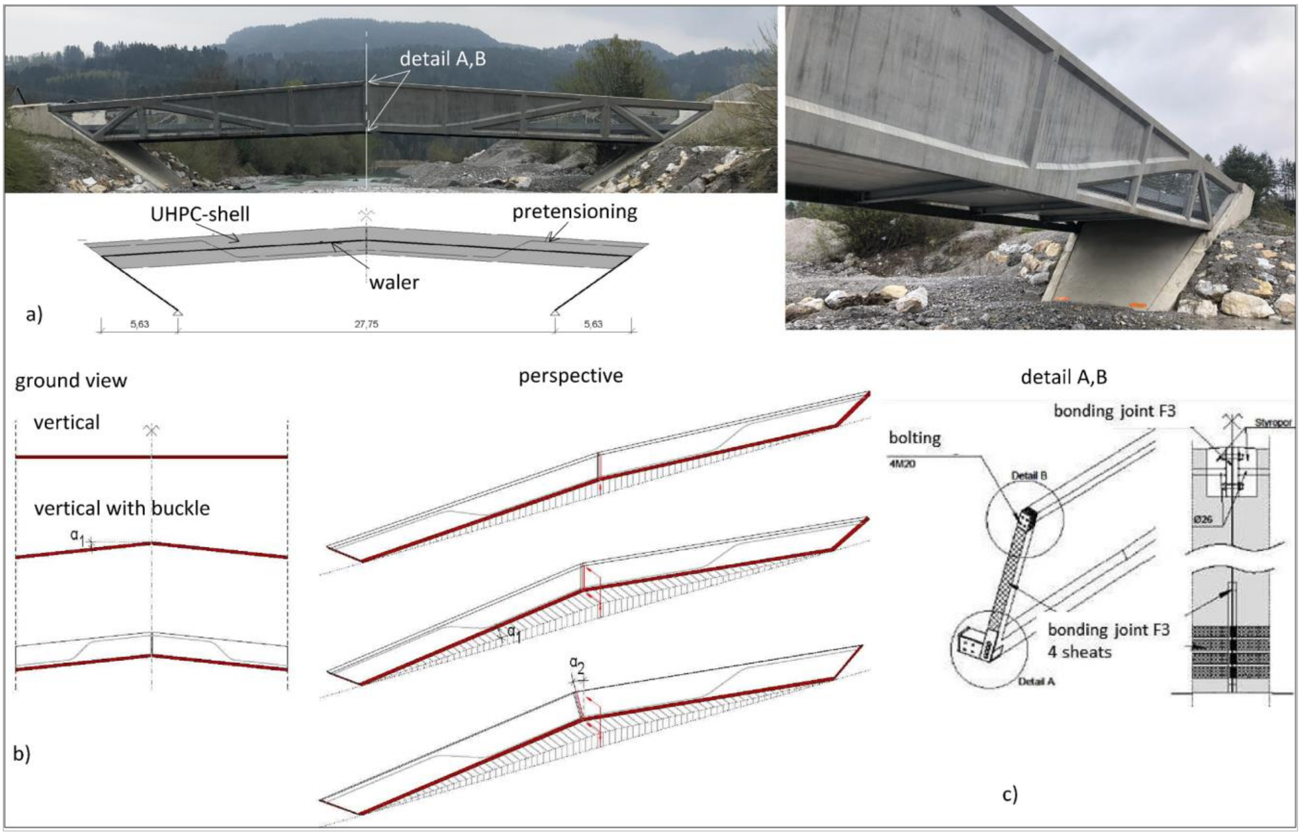

Figure 7. Paulifurt bridge in Austria [6] a) View frame
b) Spatial structural behavior frame transom
c) Detail wet joint bridge center

4.2.2 Flood protection elements

In a preliminary study on mobile flood protection systems [8] carried out by the Disaster Management Research Society in Austria, systems used so far have been analyzed, laying the foundation for further development towards planar precast elements that offer advantages in terms of both static and material technology over conventional flood protection systems. The stability of the water protection wall is accomplished by a special spatial folding arrangement of the precast elements (Figure 8a). For this purpose folded pressure and tension elements with a plate thickness of 40 mm to 50 mm are used. The shape of the individual tension and compression elements corresponds to the manufacturing process of the base element according to chapter 3.1 with a centrally arranged, vertical (= tension element) or 1: 5 inclined (= compression element) folding edge and triangular surfaces arranged on both sides (Figure 8a).

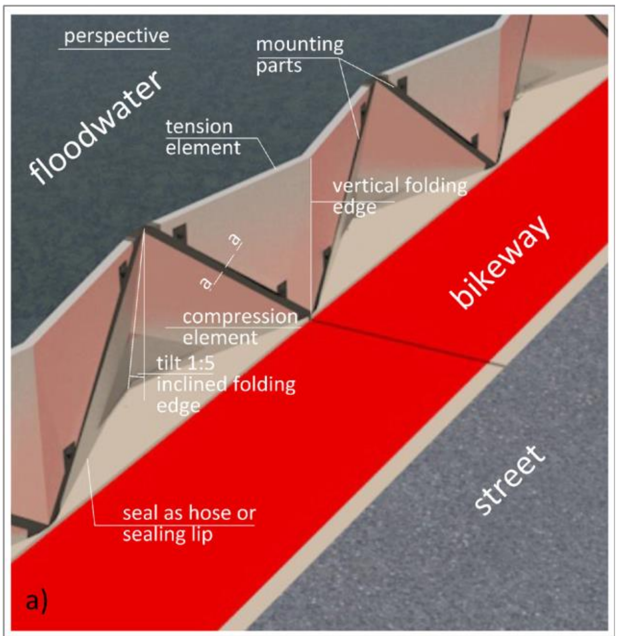

Figure 8. Flood protection element
a) Compression and tension element

Due to spatially stable arrangement of pressure and attached tension elements anchorages in the ground compared to existing systems are not necessary. The total height of the flood protection wall can be up to 1.25 m, resulting in individual element weights of 100 kg to 170 kg. In a first step the compression elements are mounted on vertically adjustable feet. In a second step the tension elements are placed on the pressure elements via a groove-shaped plug-in connection (Figure 8c) and screwed. The mechanical screw connection additionally protects against lifting of the tension element.

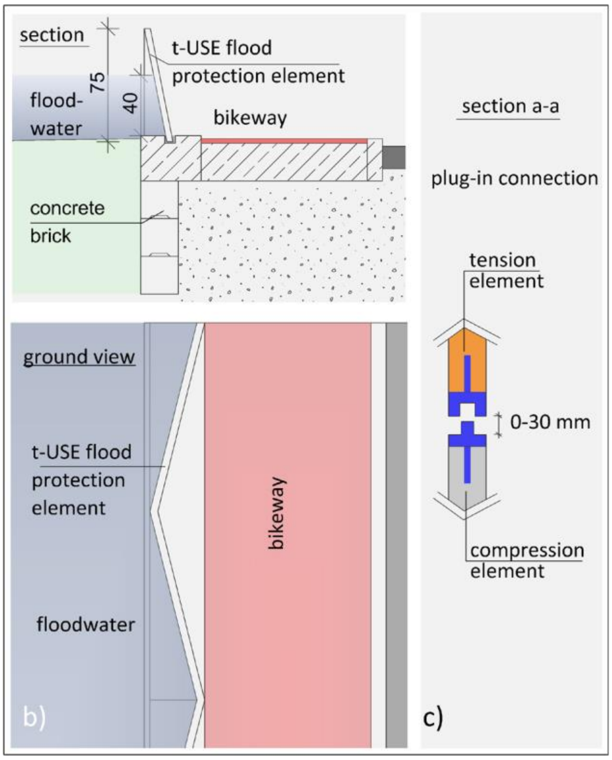

Figure 8. Flood protection element
b) Section and ground view
c) Detail plug-in connection

4.3 Building constructions

In building constructions the same requirements apply to the design task with precast elements as in civil engineering. The durability requirements of the structural elements are not given to the extent that e.g. for infrastructure projects. Thus in a first consideration a significant argument in the use of a high-quality and durable building material and is currently limited primarily to applications where direct weathering of UHPC-precast parts is given. Due to the possibility of serial production of the USE-elements and the simple assembly by means of flexible norm connections made of steel and their advantages in a life cycle analysis, there is at least the possibility of a renewed upswing of this design for a larger use in building construction.

4.3.1 Balconies

Balcony elements with t-USE-elements are connected directly to the balcony slab via a rigid connection type (Figure 9b). The folded structure of the elements results in optical advantages of light and shadow effects over conventional straight railing structures. By using white cement in the production of UHPC, pigments can be mixed to create different shade of colors of elements, creating additional architectural and aesthetic possibilities in the design.

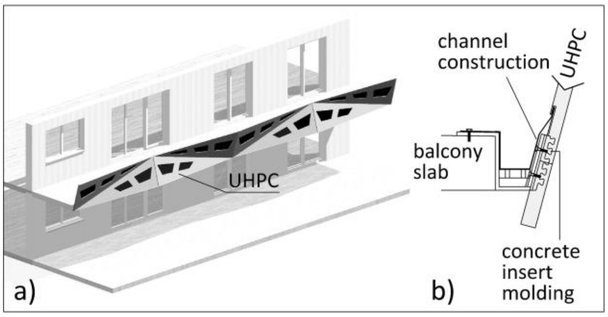

Figure 9. a) Canopy elements
b) Inflexible connection type

The built-in components, which are already delivered ex works in the element with connection possibilities by screwing allow easy installation.

4.3.2 Canopies

Canopies or smaller roofs in the outdoor area offer a further application possibility, whereby due to the dense microstructural properties of the UHPC up to the later to be supplemented joint designs (Figure 10c) no additional sealing underlayer is required.

The garage canopy (Fig. 10a) has free spans of approx. 8 m and these surfaces must be adapted by means of steel tension and compression elements. The fold-like shell elements made of prefabricated elements with a thickness of d = 60 mm form a planar support which basically rests on wall plates. Where no support on wall panels is possible and a transverse support is required, adaptive steel elements are used on site. This makes it possible to achieve larger openings on the support edge of the folding elements.

The connection of the elements with each other is made by flexibly mountable norm connections that are subsequently potted with a high-performance mortar (Figure 10c). The grouting area is protected from the effects of moisture by an additional sealing layer (for example bituminous membrane or foils).

In the canopy in the entrance area (Fig. 10b), the element is designed as a cantilever, whereby the necessary tension elements are already cast in the element at the factory. The elements can also be combined with glass elements, whereby laterally mountable brackets at the edges create support options for the glass construction (Figure 10d).

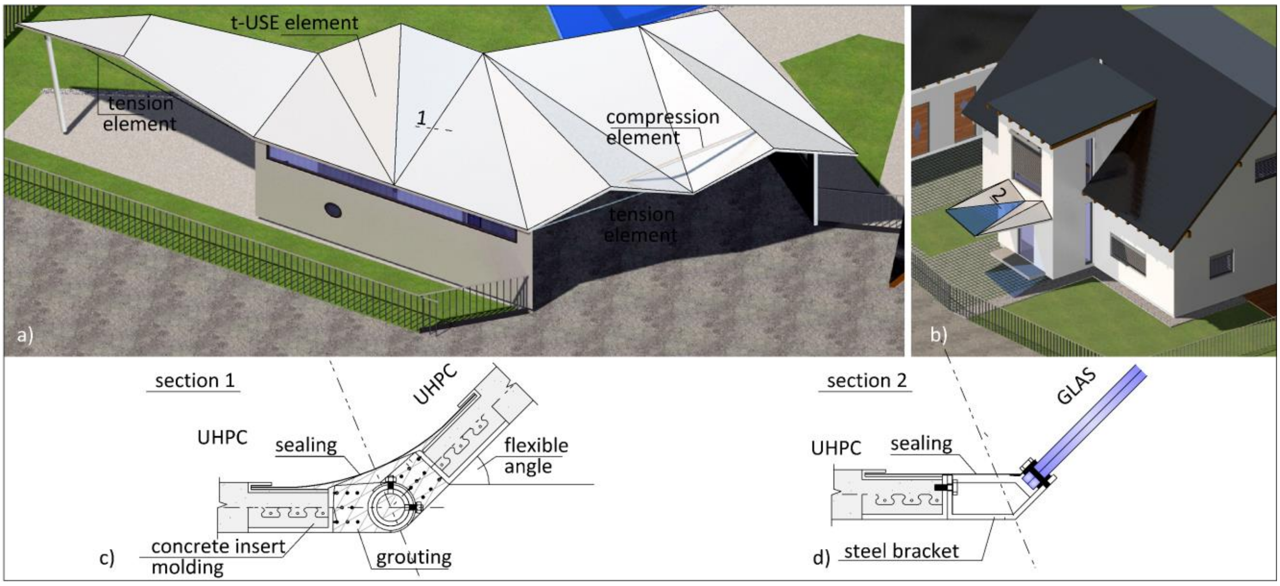

Figure 10. Canopies a) Garage canopy b) Canopy c) Detail UHPC-UHPC d) Detail UHPC-Glass

In order to estimate the primary energy consumption or global warming potential of this 60 mm thick UHPC-roof construction with a comparable conventional reinforced concrete slab construction with a thickness of d = 25 cm, a comparative calculation according to [9] was carried out on an area of 1 m². Specifically, the total embodied energy in [MJ / m²] or the global warming potential (GWP) in [kg CO2-Aq./m²] according to known data sources for a conventional reinforced concrete slab C25/30 with d=25 cm , reinforcement content of 25 kg/m² and a UHPC 130/150-plate with d=6 cm, with a variable microfiber content of 2.5 vol.% and 3.0 vol.% determined. The chosen system limits include the production of the concrete including the extraction of raw materials until the installation of the finished product. The result for the UHPC-roof construction is heavily dependent on the microfiber content, with the primary energy total between 97% and 108% and the global warming potential GWP between 94% and 103% approximately equal to the energy input of a 100% reinforced concrete slab. It can thus be assumed that the energy consumption comparison based on GWP in [MJ / m²] behaves approximately the same as a material cost comparison in [€ / m²] of both types of construction. The main advantages of a design with UHPC-precast elements compared to a conventional reinforced concrete design are therefore less effort for the roof construction costs by omitting an additional seal, in lower cost consequential costs for support and foundation construction. Another important advantage is, as already mentioned, in the increased durability of the UHPC-building material compared to a conventional concrete. This advantage, of course, is higher in directly weathered constructions, as in the examples shown.

5 Conclusions

The use of UHPC prefabricated elements for architectural elements, civil engineering and in building construction shows the versatility of this construction method. Undoubtedly the main advantage is the durability of the UHPC-building material. A material-oriented planning with the building material UHPC leads to resource-efficient and therefore sustainable constructions. The savings in material costs due to the efficient design creates a nearly balanced primary energy balance in comparison to conventional reinforced concrete constructions in building construction applications. The advantages result from the savings in the subsequent constructions of low weight, increased durability and aesthetically demanding constructions. The hidden added value of designs with good design is usually much higher than this can be represented immediately after construction. A design approach based on the NEA-principle [5] allows to create beautiful shaped structures which also give the engineer the feeling to contribute with their work positively to the built environment.

6 Acknowledgements

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