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Outline Report: **Research Project SF-10.08.18.7-09.32**
"Adhesive bonding technique in building construction – conceptual design and assistance in measuring technology during the construction of a large-scale demonstrator"

Client: **Federal Institute for Building, Urban Affairs and Spatial Research in Federal Office for Building and Regional Planning**

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1 Objective of research project

At the Technical University of Kaiserslautern, a settlement of large demonstrators (see Figure 1) named "Small House Village" is going to exist. These model structures offer the possibility to test new innovative construction methods, which were developed under down-scaled laboratory provisions, under real environmental conditions at true buildings.
In addition to the investigation of the long-term behaviour, the practicality of the manufacturing process of buildings with a ground plan of 5 x 7 m can be tested.
The focus of the research project is put on the practical testing and implementation of experiences gathered so far at the TU Kaiserslautern in the field of adhesive bonding. In the past, new insights into the interaction of different material partners by adhesive bonding could be obtained by adhesive joining. So, for example, suitable adhesives and pre-treatment procedures could be found for the adhesive bonding of steel to concrete, steel to glass or FRP-concrete components.[1,2]

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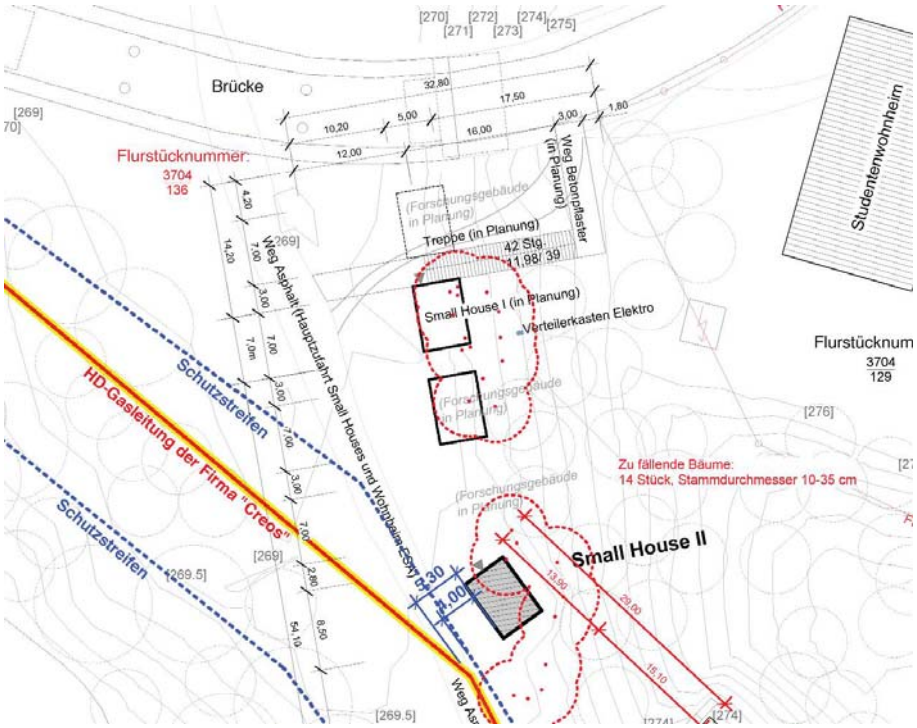

Figure 1: Part of site plan

The large-scale demonstrator "Small house II, Adhesive bonding technology in building design and construction" also allows the development, implementation and review of a comprehensive metrological program to capture the climatic boundary conditions, as well as the deformation behaviour of components joined by adhesive bonding.
It aims to open up previously unattainable areas of application for glued constructions in the construction industry and to offer new opportunities with new innovative construction methods in an ambitious architecture.

[1] Schnell, J.; Geiß, P. L.: „Light Building with Concrete-Innovative adhesive-bonding technology for filigree facade panels made of high-performance concrete”, Final BBR-Report, 2009.

[2] Geiß, P. L.: "Teiltransparente tragende Verbundbauteile aus Stahl und Glas", IGF-Projekt Nr. 15058 N / FOSTA P740. „Semi-transparent composited building components made of steel and glass“. IGF-Project Nr. 15058 N / FOSTA P740.

2 Implementation of the research challenge

2.1 General introduction to the construction method

A ventilated façade system is used. This system prevents an heat build-up and protects the underlying layers (thermal insulation and load-bearing slab) by the drainage of moisture.
Als Vorsatzschale dienen filigrane Platten aus glasfaserverstärktem Feinkornbeton (d= 12 mm), die liegend in einem Spritzverfahren hergestellt werden. Neben dem Wetterschutz bietet diese Betonfassade die Möglichkeit von der Geometrie der Tragschale abweichende Fassadenformen zu gestalten. Scharfkantige offene Fugen können in beliebiger geometrischer Form realisiert werden.
Filigree panels made of fibreglass-reinforced fine-grained concrete as facing panels (d = 12 mm), having been manufactured by a spraying procedure in a resting position. In addition to the weatherproofing this concrete facade offers the possibility to facade forms differing from the geometry of the load-bearing slab. Sharp-edged open joints can be realized in any geometric shape.
The connection between facing panel and load-bearing slab consists of glass-fibre reinforced synthetic rods (FRP). During manufacturing in the precast plant, thermal insulation, which works at improving the thermal and/or sound insulation capacity, is put into the fresh concrete of the load-bearing slab. The fiberglass rods are pressed at a pre-drilled grid through the thermal insulation into the fresh concrete. The replacement of the commonly used steel anchors or frames by lightweight, low heat-conductive and corrosion resistant fiberglass material allows, in addition to the material cost savings and the reduction of eat flux, a durable and sustainable construction.

2.2 Architectural design and planning

In the draft design, subdividing the facade into triangles and trapezoids is based on the principle of horizontal and vertical cuttings of the cube; the lines represent the joints of the facade. By variation of cutting angles and spacing of the section planes different sized pieces of the facade are formed and define such like a formal tension in the appearance.
Individual pieces of the facade are formed as frameless windows and provide -in addition to the function of incidence of light- a more asymmetrical pattern of areas. The entrance is formally produced such like, too. An embedded frame (stainless steel or other metal, in contrast to the concrete facade surfaces) underlines as an additional element the access function (see Figure 2).

Figure 2: Visualisation of large-scale demonstrator „Adhesive bonding technology in building design and construction

When transmitting the draft design into the building permit documents and into the construction drawings the cutting planes creating the formal image were slightly modified in order to avoid the occurrence of too large (too big area in an element) and too small (too few adhesive spots) facing panels.

The manufacturability of asymmetric windows (form-following frames with glued-on glass surfaces, tinted insulated glass) and its installation options were checked positively during planning implementation.
Arrangement, integration, installation and connection of solar collectors were solved in concept and in basic detail.

2.3 Development of design details

Within the scope of the research project all design details relevant for the construction of the large-scale demonstrator (roof structure with solar panels, windows, demonstrator cube, foundations, etc.) have been developed. Due to the large amount of detailed solutions, the following deals with such issues like the concerning adhesive technology of components as well as the scheduled metrological monitoring only.

Glass-concrete-steel composited beams

While chemically cross-linked structural adhesives successfully have proven themselves for many years in the field of fixings consisting of bonded metal anchors using dowels in boreholes in the construction industry, composites made by adhesive bonding with load-bearing function across surface bonding are today still an exception. The reasons are often a lack of experience in the long-term behaviour and with the resistance of the bond under climate influence and the resulting reservations for the technical approving.

The excellent long-term durable adhesion of silicone adhesives to the SiO network of inorganic glasses, which, among other things, was crucial to the limitation of ETAG 002 to this special group of adhesives, can be achieved today through the application of bonding agents and the modification of other base polymers with reactive groups of silan components comprised in modern adhesives. There is a wide range of adhesive systems available that can be used to realize long-term durable and material-saving constructions for the construction and use in glass-concrete-steel composite beam systems.

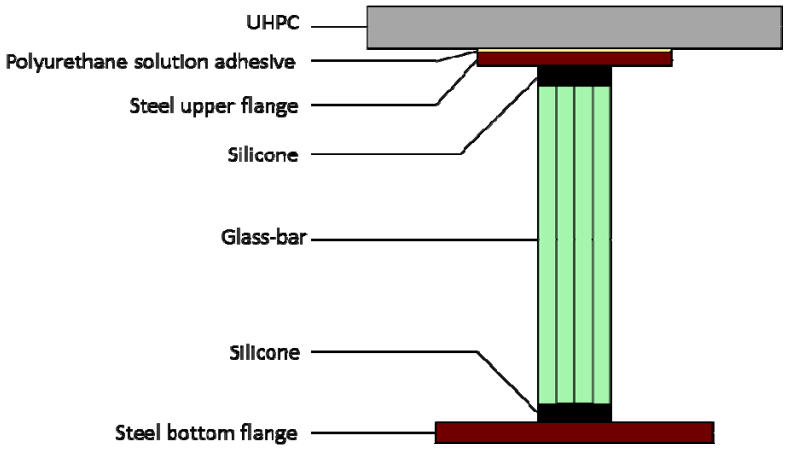

Figure 3: Arrangement of composite beams

The mechanical properties of adhesive bonded joining on the mechanical behaviour and the durability are determined in particular by the structural design of the joining locations, the type of adhesives and the state respectively the pre-treatment of surfaces to be bonded.
The use of glass girders in the construction industry is already state of the art. You will find its application as both vertical and horizontal bending beams in facade constructions or structures working with structural glassing. They carry forward, for example, dead loads and wind loads in constructions by bending to substructures. Limited by the ability of glass to take tensile forces only and to fail spontaneously by exceeding the limits of resistance bounds are set with regard to the capable load, as well as the dimensions of these elements.

The behaviour of beams made of concrete materials is characterised by the fact that the compressive strength of the concrete is several times higher than its tensile strength. Within classical reinforced concrete elements embedded reinforcing steel bars provide a sufficient strength in the tension zone of beam elements charged by bending. Structural steel construction bending beams usually consist of rolled or welded profiles which are known by their characteristic double-T or even I-shape. This geometry is capable to bridge wide spans and to carry loads by bending. The moment of inertia around the designated bending axis is decisively defined by the height of the web as well as the Steiner terms of the outer flanges.
A combination of these types of beams, a web made of glass, a bottom flange made of steel and a top flange made of concrete forming a glass-concrete-steel hybrid girder produces a variety of benefits. Not only stabilizing the glass web, as well as increasing the bending capacity achieved by the coupling of the elements would than result by the sum of the capacities of the individual elements.

Adhesive bonded facade panels

The anchors (Ø 12 mm) used come from the ComBAR ® program of Schöck-company; these parts consist of a vinyl ester resin with approx. 70-80% glass proportion (see Figure 4). The ComBAR ® FRP plate consists of a fiberglass-reinforced, partially crystalline polystyrene with a modulus of elasticity of approximately 10 MPa and a melting point of about 300° C. Both resins are tested for their durability by the Schöck-company.
Different adhesives for the joining of concrete-FRP were tested. Elaborate laboratory tests, such as adhesive tensile strength tests with a dowel extraction tool (see Figure 5) and computational models, have shown that the structural stability of the facade system with appropriate sizing of the adhesive bonded surfaces is given. Mechanical as well as economic criteria were taken into account in the selection of the adhesive.

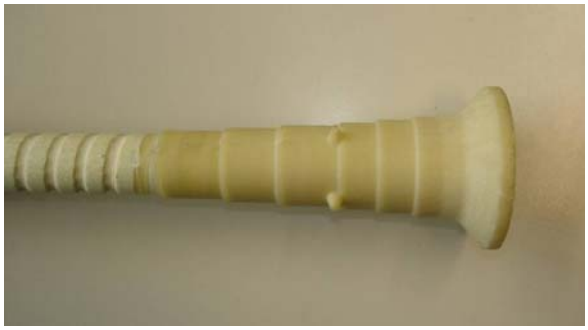

Figure 4: Schöck ComBAR® FRP anchor- FRP rod with head

Figure 5: Adhesive tensile strength test of FRP-concrete bondage

In due course of the international construction fairs Deubau and Bautec providing a demonstrator for its exhibition stand was requested by the Federal Institute for Construction, Urban Affairs and Spatial Research (BBSR). The wall intended for exhibition, which represents a building corner of the later "small house", was created in the months of November and December 2011. When producing this wall, the construction process for the creation of small houses could be rehearsed at the same time. Fabricating the sample wall provided valuable information for the later construction work on a large scale.

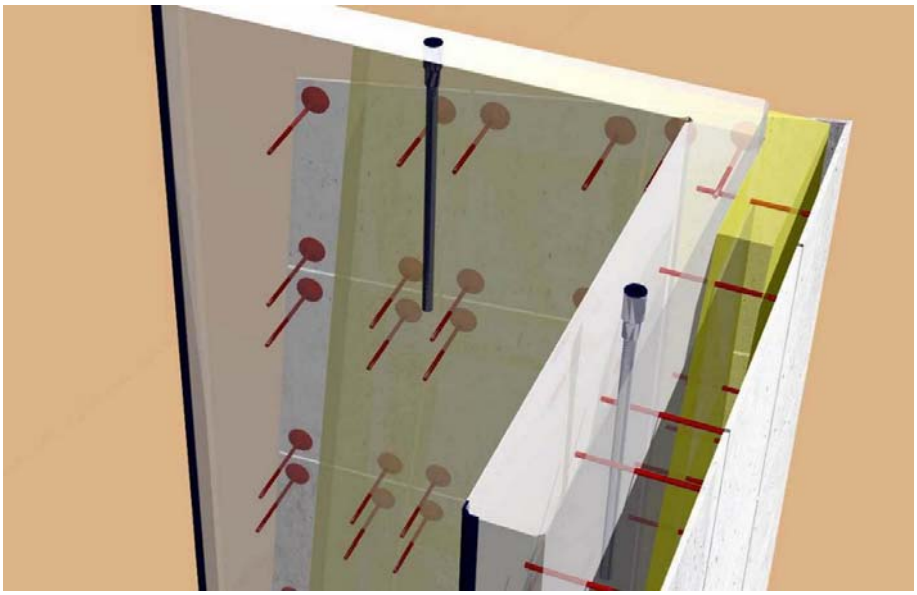

Figure 6: Draft design

After closing the two trade fairs the sample wall was transported back to the TU Kaiserslautern and was erected next to the planned site of the "small houses". Figure 7 compares the drafted visualization with the truly built object.

Figure 7: Comparison of design and execution

Measuring technology

Beyond development of the ventilated wall cross-section, long-term measurements within the building in terms of the actual penetration of damping and the re-drying behaviour during weathering (gradient) and the indoor and outdoor climate (heating and cooling of components, comfort) are going to be imperative.

Establishing a measurement program to accommodate structural characteristics is done in accordance with DIN EN ISO 7726. The measurement program consists of:

- determination of the referred material characteristic values of building materials used replicating samples in the laboratory,
- measurement of temperature and humidity within the building component with e. g. some combined temperature/humidity sensors at one measuring point each in all directions, as well as at the roof,
- registration of indoor climate (ambient air temperature, operating air temperature, surface temperatures, relative air humidity, air speed),
- recording of outdoor climate (outdoor air temperature, relative humidity, global solar radiation),
- determination of heat flows into the building and out of the building.

The measurements ought to be made with the help of independent data loggers in fixed time intervals. The data processing is performed regardless of location in a connected PC or via W-LAN at choice.
In addition to the measurements on subject of building-physics of the building, the joining’s are subject to metrological examinations. The dimensioning of the joining’s and the grid of joining media is based on verification in the ultimate limit state of load-bearing capacity. The required resistances of joining means have been concluded from short time testing. As a criterion for serviceability is the durable fixing of facade panel locations. Just by that an everlasting pattern of joints can be guaranteed for the lifetime of the building. Measurements on the maximum claimed GRP-connectors are carried out to investigating the deformation behaviour. The vertical displacement of the façade panel is taken via an inductive position transducer. The anchor rod itself is subject to bending. The maximum stresses occur at the clamping point in the concrete. In this area, strain gauges (DMS) are fixed both in the tension zone as well as in the compression zone.

3 Summary of results

Ventilated facade systems provide an optimal structural solution for exterior cladding and meet all requirements of both aesthetic and functional points of view. The facing panels protect the underlying heat insulation from weather; the hollow space between façade panels and insulation dissipates penetrated moisture from inside or outside.
Designing and erecting of the sample wall for the exhibition stand of the Federal Institute for Construction, Urban Affairs and Spatial Research (BBSR) international building fairs Deubau and Bautec provided important insights that can simplify the construction process in the upcoming production of the large-scale demonstrator. It was also possible to observe and analyse the adhesive bonded joining under the influence of weathering over a whole season cycle.
The whole thing has shown that the substitution of conventional fastening methods by adhesive bonded joining allows a reduced thickness of the facing panel (12 mm). When using conventional fastening technology the facade plates should either be fastened by screws or by a metal frame. Adhesive bonding of wall panels onto the fasteners (RFP-anchors fitted with adhesive bonding plates) enables a much more filigree and lighter performance of facades.
The range of know-how about the application of adhesives in new constructions was expanded on glass-concrete-steel hybrid beams, in order to be able to give new impetus to structural glassing. Particularly noteworthy is that these new structural elements having gained a high level of transparency by the glass web therefore are perfectly suitable for use in light-looking constructions.
At the time of drafting this report foundations and all components, which allowed prefabrication (composite beams, bearing pockets, etc.). were/are produced. The precast elements for the load-bearing slab are -due to demand of space- going to be produced ´just in time´ in the precast plant and will be delivered for installation on the building site. In mid-December 2012 the

construction work ceased due to weather conditions and is going to be continued after the freezing period.