THE AESTHETICS OF CONCRETE

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Dedicated to Prof. György L. Balázs
for his 65th birthday

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We cover the external facades of our buildings with different materials, which significantly determine the appearance, and aesthetics of the building while meeting many requirements. The article covers the number of ways and how facades created with concrete elements, concrete cladding or exposed concrete can be shaped, and how they react to external influences and conditions.

The article examines how today's modern concrete facades, in addition to providing the necessary technical function, can give an aesthetic façade appearance or even how the façade can even represent the spirit of the building.

In addition to the already established concrete façade technologies, what new procedures are there in the construction industry and what additional possibilities are there in this material during façade use.

Keywords: concrete surface, decoration, relief, colored concrete, folded concrete, photogravure, concrete printing

1. THE POSSIBILITIES HIDDEN IN CONCRETE FACADES

The appearance of a building in space is created through the combination and interaction of various materials. The look, processing, and malleability of materials are crucial for the overall impression. When we talk about concrete or concrete structures, we primarily think of load-bearing elements and less of the beauty inherent in the material or the aesthetic possibilities. However, the architect must keep the final overall picture in mind and select the necessary materials even before the actual physical appearance of the building.

Every material has a certain visual language that the designer must utilize. The form of concrete or artificial stone is determined by the formwork. Ductile concrete can take on virtually any shape until it solidifies. Working with concrete requires great expertise and imagination from the architect, but at the same time, it also demands self-restraint, as the versatile possibilities of this material are practically limitless.

Designing a concrete facade surface means that the designer must not only consider the structural properties but also make use of the material's shaping possibilities. Surface appearances shiny-matte, smooth-rough, coarse-fine, to name just a few from the infinite variations are all dependent on the material.

Fig. 1: Concrete Slit House, designed by Atelier Zhanglei (Ghile, 2013)

These forms develop from the interaction of different materials, or they reveal certain components of a particular material.

These solutions can either strengthen or weaken the architectural language of the building but undoubtedly influence each other. They determine the optical impression, which can be further defined with the use of different colors. The *relief-like shaping* of the surface adds interesting light and shadow effects to the facades.

Surface structures can also be created through the special shaping of certain architectural details (e.g., joints, patterns). The selected appearance of the components must always be in harmony with the immediate surroundings of the building, and more importantly, with the overall urban context. Designing the facades of buildings should be considered a public matter, not just meeting the expectations of the client but also keeping in mind a more complex system of relationships in urban planning.

2. CONCRETE SURFACES AND FORMWORK STRUCTURE

Concrete consists of components such as cement, aggregates, additives, and water. After solidification, it takes on the properties, appearance, and form of rocks. Fresh concrete is poured into a formwork and allowed to set there. The imprint of the formwork appears on the hardened concrete surface, which can be either rough or smooth in structure. Various optical effects can be achieved based on the pattern of the formwork or the imprint left on the concrete. A well-known

Fig. 2: The impression of the formwork structure on the surface of the concrete (Doka, 2009)

optical effect is that by structuring with dense, vertical lines, we perceive the facade as taller and narrower.

On the other hand, a wide spacing between horizontal lines reduces the perceived height and makes the building appear broader. Irregularly oriented structures provide a flat, wallpaper-like pattern, and material structures can evoke various material associations (e.g., wood grain pattern). Some line patterns can create a perspective representation of a surface, or by varying the density of lines, a flat surface may appear either convex or concave.

3. DECORATION AND RELIEF

In addition to material-dependent surface structures, visible surfaces can also be adorned, achieving significant architectural (aesthetic) impact. Decorative forms, utilizing the third dimension, become reliefs. To create reliefs, a negative element containing the desired forms must be inserted into the formwork, defining the future pattern. Decoration provides the architect with an opportunity to break up the surface and dissolve the solid form of the building's facade and material. Reliefs can articulate, enliven, and give the building a distinctive, unique exterior. The patterns on the facade, as imprints of the negative plastic form placed in the formwork during prefabrication, endure on the concrete elements. These embellishments can appear not only on the exteriors of buildings but also as interior design motifs within internal spaces.

Thanks to the latest developments, these reliefs can now be produced through 3D concrete printing. A notable example is the ribbed concrete ceiling created by researchers at ETH Zurich. The project involved experts from the Swiss university's Digital Building Technologies (DBT), Block Research Group (BRG), and Architecture and Buildings Systems (A/S) departments. The prototype of the structure, named HiRes Concrete Slab, was installed in one of the university's offices used by robotics researchers. According to their claims, beyond its relatively thin and uniquely beautiful, meandering patterned aesthetics, the ceiling is also energyefficient.

The true purpose behind developing the HiRes Concrete Slab was to explore and showcase the advantages of 3D printing. During the printing of the prototype, concrete was

Fig. 3: HiRes Concrete Slab (Aouf, 2022)

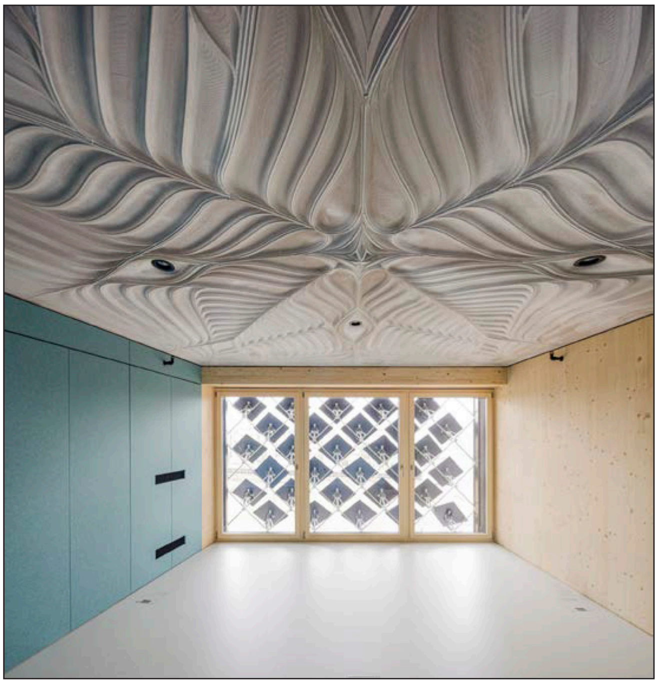


Fig. 4: Concrete slab (Aouf, 2022)

poured into 43 forms, each 50 mm thick, using 3D technology. The thickest parts of the ceiling, reaching a maximum of 300 millimeters, are at the intersections of the modules. The forms were supported by a laser-cut wooden formwork during the process.

The technology's energy efficiency is attributed to reduced material requirements and the integration of various building services during the production of the Concrete Slab, such as ceiling heating-cooling or ventilation. Developers from the Architecture and Buildings Systems department integrated four custom polymer ventilation channels into the prototype structure using 3D printing before pouring the concrete.

The shape of the tubes was designed for optimal airflow properties and minimized energy indices. Truth be told, thanks to their aerodynamic characteristics, the 3D printed ducts are much more efficient than other previous systems," explained Andrei Jipa, a doctoral student at DBT. The A/S team determined the printed patterns based on the hydraulic circuits of the cooling-heating pipes, using precise computational calculations. The result is an extremely efficient radiant surface with better thermal performance than traditional flat ceilings.

The form and size of the formwork were designed to fit into the compartment of the 3D printer and to be easily removable from the final cast. The slightly vaulted design of the modules takes advantage of the high compressive strength of concrete, and it requires less material than traditional methods. Horizontal forces are absorbed by four tensioning structures placed at each corner of the module. Additionally, the ribbed design provides natural sound diffusion/damping properties, which are essential in today's communal, open-plan offices, or conference rooms.

4. COLORED CONCRETE AND COLORED COATING

Interesting shape-forming effects can be achieved with the application of colored concrete elements. In such cases, colored pigment is added to the concrete mix. For red, yellow, brown, and black tones, mainly iron oxide pigment is used, while for green shades, chrome oxide and chrome oxide hydrate pigments are employed. Blue tones, on the other hand, may utilize a mixture crystal-based pigment such as cobalt-aluminum-chrome oxide. Concrete coloring is durable and weather-resistant. When using gray cement, the color

Fig. 5: Mahadeva Prayer Space, Designer: Karan Darda Architects (Szilvási, 2019)

Fig. 6: The white chapel forms a perfect unity with the landscape (Szilvási, 2019)

Fig. 7: Teotitlan del Valle Community Cultural Center building (Szilvási, 2019)

tone is darker, whereas with white cement, it is lighter and cleaner. Fine surface detailing further enhances the color. To highlight larger surfaces on a building, similar surface sections or individual building elements can be colored. However, the used paint must always be in harmony with the properties of concrete. Increasingly, visually appealing concrete surfaces with colored materials are appearing on the facades of buildings, emphasizing the aesthetic value of concrete. In the previous part of our article, we presented the use of white concrete; today, we focus on red concrete.

The prayer space was designed by the Indian firm Karan Darda Architects using locally producible materials. Local architects constructed the temple of Mahadeva (Shiva), the most important Hindu deity, using red concrete. The modern reinterpretation of the red concrete prayer space reflects the traditional rural Indian temple architecture. In this environment, the rough finish of the surface, the occasional irregularities in joints, and the color variations in the concrete do not adversely affect the appearance of the structure. The prayer space is placed on a yellow-gray concrete slab, separating it from its surroundings. The differing color palettes of the building and the base plate harmonize with the environment, where the red concrete also serves as the focal point of depth.

The architecture of Lima has exceptionally expanded with a beautiful university campus. The university building was recognized with an international RIBA award in 2016. The building's perforated concrete block, with its silky white appearance, connects Lima to the sea like a modern Machu Picchu. The design of the building was conceived by Iwan Baan, a designer at the Grafton Architects studio. Concrete appears on the facade and in the interior, becoming part of the interior design. The flawless joints of the large-panel formwork and the imprints of spacers stand out on the facades, and their regular layout is an integral part of the architectural spectacle. The concrete surfaces are homogeneous whites, free from bleedings and irregularities, providing a true visual concrete experience. The outer edge of the building rises like a rock above the cut with its height and articulation. The inner part is built down in terraces to the ground floor.

The architectural firm Productora designed the Community Cultural Center building in Teotitlan del Valle, Mexico. The concrete of the building carries the colors of the rocky desert environment, where the local rock aggregate added to the mix gives the concrete a yellowish hue. The texture of the formwork wood also appears on the surface.

Another option is to paint the finished concrete surface in the desired color. Paint can be applied directly to the facade concrete surfaces. The paints that can be applied to concrete surfaces must meet the following requirements:

- resistance to alkaline effects coming from the concrete
- good adhesion to the concrete
- good bonding within the coating system
- repaintability with the same paint
- weather resistance
- resistance to industrial environments and/or water-soluble substances
- light and UV resistance
- low susceptibility to pollution
- satisfactory vapor permeability
- resistance to flowing water
- resistance to washing or scrubbing.

Among the paints, primarily mineral and silicate paints that cure in the air or hydraulically, as well as plastic-based dispersion or polymerized resin-based paints, can be considered. When selecting the paint, it is important to consider that repainting may be required periodically. Colors cannot replace deficient architectural design, but they can be well-utilized as aids and supplements. The method of coloring can be material-dependent or independent. The goal may be to achieve an effect related to semantics or integration into a larger context. The design of the facade color scheme should be an essential component of every construction and permit plan.

5. STONE-CARVING-LIKE AND OTHER PROCESSING OPTIONS

In stone-carving-like processing methods (such as bush-hammering, grooving, and sandblasting), the top layer of cement is removed from the concrete. This results in a rough surface that reveals partially fractured additives. The use of white cement, colored additives, or colored paint can achieve special effects, enhanced by light and shadow effects.

Another method of processing concrete surfaces is scraping, sandblasting, and flame treatment. In these methods, the top layer of cement and the additive, serving as a shaping element, are removed. In scraping, individual additive particles are exposed and cleaned. Sandblasting creates a rough surface, while in flame treatment, the heat causes the top additive particles to burst, resulting in a jagged surface. The additive structure becomes visible through grinding and polishing of the concrete surface. Concrete stones processed in this way can be versatilely used, for example, in facades, walls, and even window sills.

6. WASHED CONCRETE AND EXPOSED AGGREGATE CONCRETE SURFACES

The most commonly used technique for surface treatment is washing away the top cement layer, a process in which the cement mortar is removed from the top layer of concrete using

Fig. 8: Stone-carved-like facade concrete, Grand Tokaj Winery (Kis, 2016)

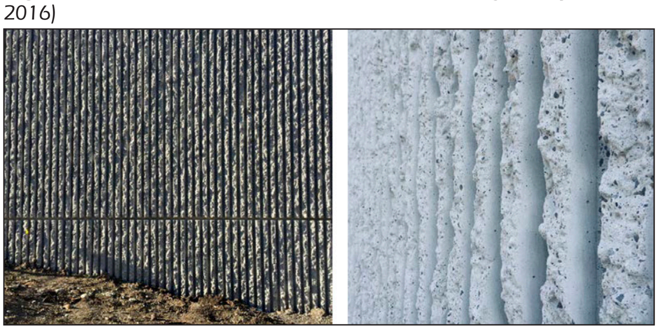
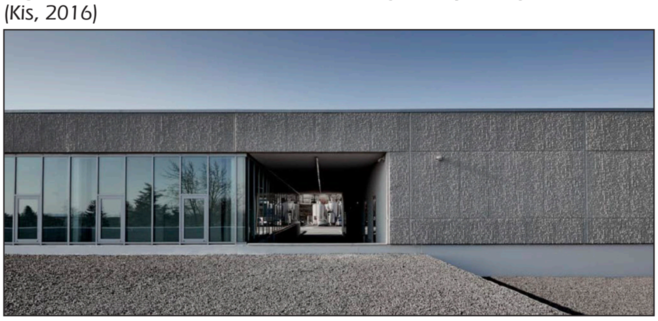


Fig. 9: The concrete facade of Grand Tokaj Winery, Designer: Péter Kis (Kis, 2016)



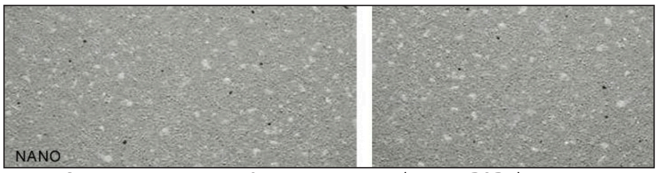


Fig. 10: Nano-particle surface appearance (Reckli, 2021)

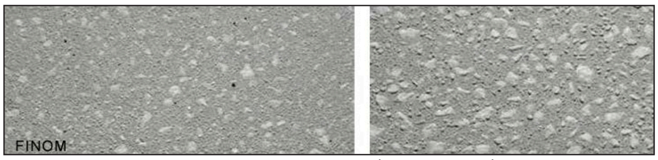


Fig. 11: Fine-washed concrete surfaces (Reckli, 2021)

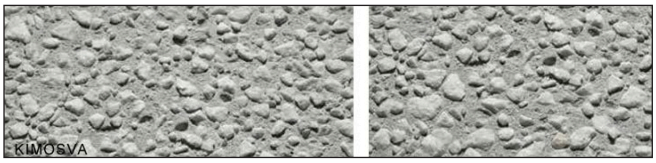


Fig. 12: Coarse-washed weathering on the surface (Reckli, 2021)

high-pressure water or wire brushing. This reveals the stone aggregate used in the concrete mix.

The procedure allows achieving various washing depths, resulting in surfaces with increasingly distinctive appearances. Another option is to achieve different effects by using various additives with different properties and colors. The appearance of the concrete is always different depending on whether angular or rounded, light or dark, monochromatic or colored stones are mixed with the additives.

Another method involves applying surface retarders to the inner side of the formwork. This allows only the top millimeters of the surface to be washed out, a technique known as exposed aggregate finish. This gives the concrete a very interesting sandstone-like appearance, which can be further colored with appropriate additives and pigments.

7. FOLDED CONCRETE BUILDING

In the design of large-scale concrete facades, not only the imprint of patterns but also the shape of the elements can have a powerful visual impact, as seen in the manufacturing and office building of the Textilmacher company in the industrial quarter of northern Munich.

Its iconic appearance is attributed to the geometrically precise folded facade. A fascinating aspect is that, with the changing periods of the day, the interplay of light and shadows gives the building varying aesthetics. The anthracite gray matte concrete surface harmonizes with its surroundings. Besides the

Fig. 13: Large-panel concrete facade, Designer: Tillicharchitektur (Compensis, 2013)

advantage of prefabrication, the large-scale facade cladding offers a short construction period and cost effective conditions. The elements were transported to the site after production and intricately fitted together like a puzzle.

8. EMERGENCE OF NEW TECHNOLOGIES

8.1 Photogravure concrete surfaces

A new technology for displaying custom photos on concrete surfaces is called “photoengraving.” The process involves scanning the photograph(s), increasing their resolution, digitizing them with software, and then carving the pattern into so-called “master plates.

Using the master pattern created in this way, a formwork for photoengraving with a flexible pattern is produced. The completed formwork can then be used either at the precast concrete plant or on-site during concrete pouring. After removing the formwork pattern, the photograph appears on the cast facade concrete surface.

8.2 Striped, printed concrete surfaces

By utilizing the latest technologies, new textures are emerging, such as a residential house created with a 3D printer that aims to exploit the malleability of concrete. Thus, in the suburbs of Eindhoven, the Project Milestone, a complex of five buildings constructed using 3D printing, has been established, considered Europe’s first 3D-printed residential complex where people actually live. The project involves printing a complex of five buildings.

The city decided back in 2017 to build with 3D technology and subsequently lease houses that meet all comfort requirements. The buildings, designed in a wooded park environment, are sustainable, energy-efficient, comfortable, lightweight, and quiet. In 2017, they already constructed a pre-stressed concrete bridge for cyclists, printing it from 800 layers. The bridge was printed at the Eindhoven University of Technology, which is at the forefront of concrete printing research and played a role in implementing the Milestone project.

The first building will be a 95 sqm, single-story house with three rooms, and they aim to complete it in the first half of 2019. The other four buildings will be multi-story houses. The elements of the initial buildings will be created with the university’s 3D concrete printer (3DCP), while for the last house, they plan to use an on-site printer. The development and implementation of this on-site printer can be a crucial step for

Fig. 15: Photogravure image on concrete surface, Quebec, Canada (Építési Megoldások, 2023)

Fig. 16: Project Milestone visual plan. Designer: Witteveen+Bos (Dery, 2018)

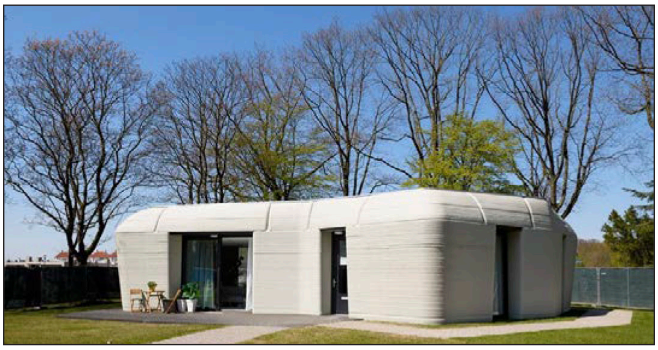


Fig. 17: Project Milestone: the first completed house. Designer: Witteveen+Bos (Sebes, 2021)

Fig. 14: Photogravure facade concrete surface (Építési Megoldások, 2023)

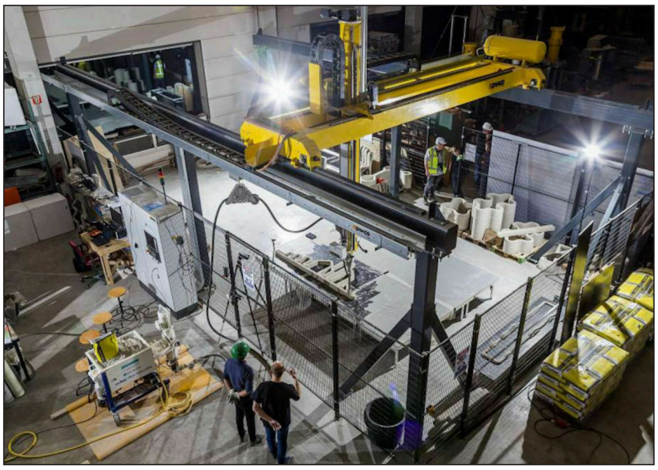


Fig. 18: Concrete elements 3D printing (3DCP) at Eindhoven University of Technology (Project Milestone, 2019)

the technology's future widespread adoption. One advantage of 3D-printed buildings, as seen in the renderings, is that the designers have planned futuristic, free-form structures that fully utilize the possibilities offered by 3D printing. These unique free-forms are challenging and expensive to achieve with traditional technologies. Another significant advantage is the reduced need for concrete with this technology. In traditional concrete pouring, the concrete completely fills the formwork, while here, concrete is printed only where needed. This translates to less cement usage, potentially reducing overall construction costs and contributing to lower carbon dioxide emissions, as cement production is associated with high CO_2 emissions.

The structure's additional advantage is that its operation requires only a few people, and the printer head and printing results are monitored by a camera. Thus, a double-layered wall of 1 m^2 can be completed in 5 minutes. The technology provides great freedom for design, as, unlike traditional methods, the 3D printer does not pose technological challenges even for organic curved forms.

Since the beginning of the project, the same technology has been used to create Europe's largest residential building in Wallenhausen, and the first such residential building in Tempe, Arizona, in the United States.

9. RESISTANCE OF CONCRETE FACADES TO DIRT AND WEATHER

When creating a durable and aesthetically pleasing building facade, it is important to consider the inevitable accumulation of pollutants over time and ensure proper drainage of rainwater on the facade. Concrete elements used to cover facade surfaces are grateful structures in this regard.

The direction and strength of the wind determine how much water can accumulate in certain areas and where dirt deposits may form. The flow pattern of water is crucial, as it allows pollutants to be washed out of the facade surface, and under certain conditions, some of them may redeposit elsewhere.

The slope or inclination of the concrete surface is equally important. Vertical surfaces receive relatively little water and are easily cleaned. The amount of rain falling on surfaces leaning backward is much greater. However, their cleaning ability is somewhat lower, and pollutants often accumulate on the lower edges. Forward-leaning surfaces generally remain dry and are the least prone to contamination. The upper part must be designed so that water cannot flow onto the surface, as otherwise, the flow pattern becomes evident very suddenly and can compromise the appearance of the facade. Taking these conditions into account is an essential basis for shaping facades with concrete. Properly designed elements can effectively prevent the facade from getting dirty over time.

Fig. 19: Facade of the Vienna University of Economics and Business Library (Hadid, 2013)

A facade of the Library and Learning Center of the Vienna University of Economics and Business is made with FibreC concrete cladding – glass fiber-reinforced concrete elements dominate the appearance of the building designed by Zaha Hadid. The two interconnected main parts of the building are made unmistakable by their appearance: black for the public space and white for the private space. The architect chose glass fiber-reinforced concrete elements as the distinctive material for the facade.

In any case, as seen from the examples mentioned, concrete facades do not lag behind more traditional brick, stone, or other claddings in terms of appearance, durability, weather resistance, and cost-effectiveness. They provide an aesthetic appearance for almost any type of building.

10. CONCLUSIONS

Concrete is becoming increasingly popular and diverse in appearance on facades and interiors alike, allowing for the creation of durable, simple, yet elegant and striking surfaces. It is even capable of initiating trends. Thanks to the latest technologies, it is now easy to retroactively create exposed concrete surfaces.

The examples presented highlight the many ways in which we can shape the facades of our buildings to adequately represent the spirit and appearance of the structure. These external concrete facade surfaces represent great flexibility in formability during production, solidifying to provide proper protection for internal spaces.

They do not only meet technical necessities such as weather resistance, heat effects, sunlight, precipitation, wind effects, moisture effects, protection against contaminants and chemical effects, mechanical protection, frost resistance, shape and size durability, fire safety, color retention, durability, easy maintenance, and space separation, but also serve aesthetic, interesting, attention-catching, and unique representation of the building's external appearance, reflecting the internal function.

With the emergence of new innovative technologies, such as concrete printing, cost savings, and reduced carbon dioxide emissions can be achieved compared to traditional concrete walls, moderating the eco-footprint of such buildings.

The wide variety of ways in which concrete facades can be shaped demonstrates the potential hidden in concrete, which, in my opinion, has not been fully exploited. Significant reserves lie in the facade usability of this material.

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