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Technological Aspects of Using Modified Gypsum Mixtures in Monumental and Decorative Art

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Abstract

The article examines the transformation of gypsum from a traditional binder into a controllable composite material for monumental and decorative art against the backdrop of its centuries-long use and contemporary performance constraints. The study's relevance lies in the demand for large-format, highly cantilevered reliefs operating under complex climatic and environmental conditions; therefore, the research aims to identify technological principles for the use of modified gypsum mixtures in this field. The methodological basis is an interdisciplinary synthesis of materials science and art-technological data, which enabled the development of a typology of polymer, hydrophobic, filled, fibrous, and organomineral modifications of gypsum and their correlation with the requirements of large-scale relief. The scientific novelty lies in conceptualizing gypsum as a designed composite with a controlled trajectory of strength, crack resistance, moisture resistance, density, and rheology, as well as in developing an original stepwise algorithm for the work of the bas-relief artist, linking the choice of mixture, application technology, and curing regimes to the life cycle of the artwork. It is demonstrated that a combination of polymer additives, light and functional fillers, dispersed reinforcement, and rheology-active components enables deliberate reduction of element mass, enhancement of the operational reliability of reliefs, and expansion of the working window of mix plasticity. The article is intended for monumental artists, conservators, and technologists working with gypsum and other decorative composites.

Keywords: *Gypsum, Modified Gypsum Mixtures, Monumental and Decorative Art, Polymer Modification, Fiber Reinforcement, Bas-Relief.*

INTRODUCTION

Gypsum as a binder for architecture and decoration has been in use for at least eight millennia: its traces have been identified in floor screeds of Neolithic settlements in the Near East, in mortars and plasters of Egyptian pyramids, in wall coverings of Çatalhöyük, and in the paintings of ancient and medieval buildings. In historical interiors, it served as the basis for smooth plasters, ornamental stucco, sculptural inserts, and bas-reliefs. It was also valued for its fire resistance and the ability to produce complex profiles directly in situ (Arnavutoglu et al., 2024).

In the modern era, especially from the 18th–19th centuries onward, the development of industrial production of building gypsum and the standardization of grinding significantly strengthened its role in decorative finishes: cornices, coffers, rosettes, and high-relief panels began to be produced in gypsum on a mass scale, and in the 20th century gypsum plasterboard and ready-mix dry gypsum compositions for interior finishing were added to these applications. This consolidated gypsum's status as a basic carrier of plastic décor in the interiors of both everyday and monumental architecture (Dams et al., 2025).

The basic properties of gypsum are closely related to its crystal chemistry: when dihydrate calcium sulfate is calcined, hemihydrate is formed, which, upon mixing with water, rapidly recrystallizes back into the dihydrate form, forming needle-like crystals that create a rigid framework. This mechanism ensures the characteristic rapid setting: for building gypsum, the standard initial setting time is not less than 3 and not more than 30 minutes, while in real compositions without special retarders, it often lies in the range of 5–10 minutes, which is convenient for small-scale modelling and fine detailing (Hao et al., 2021).

Fine grinding and high purity of the raw material determine its whiteness and ability to reproduce fine relief, which is critical for bas-reliefs with subtle modelling of light and shadow. The lower calcination temperature compared to clinker binders, as well as the possibility of using industrial by-products and recycled gypsum waste, make it possible to significantly reduce aggregate environmental impacts, as

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confirmed by life-cycle assessments and studies on gypsum recycling that demonstrate ecological advantages of gypsum systems for several key environmental impact indicators (Baran et al., 2021). At the same time, traditional gypsum mortars exhibit a pronounced porous structure: the pore volume in the hardened stone may reach 50–60%, most of which consists of submicron pores active in capillary suction (Payghan et al., 2019).

This leads to high water absorption, a tendency toward moisture saturation, and dissolution under conditions of elevated humidity and direct wetting, resulting in decreased strength, deformations, and creep, especially on vertical surfaces and in multilayer wall-painting systems (Tiennot et al., 2025). The brittle fracture behavior, sensitivity of strength and crack resistance to the water-to-gypsum ratio and curing regime, and the relatively high bulk density compared to lightweight polymeric or composite materials limit the size and cantilever projection of traditional gypsum reliefs and complicate their operation and transportation. An additional technological problem is the short working time: without adjustment of setting regimes, large volumes of mortar are challenging to apply evenly, model, and achieve the required degree of detail, as noted in contemporary studies on optimizing the composition of building gypsum (Sun et al., 2024).

It is precisely this set of limitations, under conditions of increased artistic and performance demands, that generates a persistent need for modified gypsum mixtures specifically designed to produce large-scale, structurally complex reliefs. For large panels, deep bas-reliefs and spatial compositions, a combination of increased flexural strength, crack resistance and durability with controlled working time, moisture resistance and, often, reduced weight is required. Experimental and applied studies indicate that the introduction into gypsum systems of water-soluble polymers, synthetic resin dispersions, hydrophobizing additives, mineral fillers and fibers makes it possible to form a spatially interconnected crystalline and polymer matrix that increases strength over time, reduces water absorption and enhances frost resistance, thus opening the possibility of using such materials even in exterior envelope and façade systems (Zhukov et al., 2021).

Modern dry gypsum-based mixtures with complex modifying additives occupy a distinct niche in the market, enabling the specification of rheology, setting time, and pore structure for a particular technology: from mold casting and machine application to additive manufacturing, for which special formulations with increased strength and form stability before final hardening are designed (Zhang et al., 2021). In the context of monumental and decorative art, this implies the possibility of developing the material for the artistic task: creating extended, strongly cantilevered and deeply modelled reliefs with controlled setting kinetics, improved operational reliability and a more favorable environmental profile compared to traditional unmodified gypsum compositions.

MATERIALS AND METHODOLOGY

The material basis of the study consists of a body of contemporary work on the physico-chemistry and technology of gypsum binders, covering issues of microstructure modification, fire resistance, and environmental profile of traditional and modified gypsums (Arnavutoglu et al., 2024; Baran et al., 2021; Dams et al., 2025; Hao et al., 2021; Sun et al., 2024; Zhang et al., 2021). Studies form a separate block focused on increasing water resistance and controlling pore structure under conditions of moisture exposure (Payghan et al., 2019; Tiennot et al., 2025; Ren et al., 2025; Zhu, 2024; Wang et al., 2025; Zhukov et al., 2021), as well as on polymer modification, fiber reinforcement and density reduction of gypsum composites using mineral and organic fillers (Gomes et al., 2019; Jia et al., 2021; Petropavlovskii et al., 2025; Wang et al., 2023; Anjum et al., 2025; Yildizel et al., 2025). Based on this corpus of sources, a typology of modifications of gypsum mixtures, polymer, hydrophobic, filled, fibrous, organo-mineral, and rheological, was established and used to schematize their influence on strength, crack resistance, water absorption, density, and workability (Gomes et al., 2019; Jia et al., 2021; Petropavlovskii et al., 2025; Wang et al., 2025; Ren et al., 2025; Zhang et al., 2021).

Methodologically, the work is constructed as an interdisciplinary synthesis of materials science and art-technological approaches, oriented toward reconstructing the algorithm for applying modified gypsum formulations in monumental and decorative art. First, a comparative analysis was carried out of traditional and modified systems with respect to key constraints for large-scale relief, capillary water absorption, solubility under moisture exposure, brittle fracture, density, and the working window of setting, drawing on experimental data on deformation and durability (Baran et al., 2021; Payghan et al., 2019; Tiennot et al., 2025; Zhukov et al., 2021). Subsequently, the properties of polymer- and fiber-reinforced, lightweight, hydrophobized, and organo-mineral composites were correlated with typical artistic scenarios, from highly cantilevered ceiling elements to extended wall panels in diverse service environments (Dams et al., 2025; Gomes et al., 2019; Jia et al., 2021; Petropavlovskii et al., 2025; Wang et al., 2023; Anjum et al., 2025; Yildizel et al., 2025). At the final stage, using the mixing, placement, curing and drying regimes for modified compositions described in the literature (Arnavutoglu et al., 2024; Sun et al., 2024; Ren et al., 2025; Zhang et al., 2021; Zhu, 2024), an original model was articulated for the stepwise work of the bas-relief artist, structured in the form of algorithms and interpreting gypsum as a designed composite with a controlled property trajectory throughout the entire life cycle of the artwork.

RESULTS AND DISCUSSION

In direct connection with the previously identified need to enhance strength, crack resistance, and moisture resistance for large-scale relief, polymer modification of gypsum binders is usually singled out first. The incorporation of redispersible polymer powders and aqueous dispersions (ethylene-vinyl acetate, vinyl acetate copolymers with various vinyl monomers, and polyvinyl acetate) in amounts on the order of 5–10 % by mass of the binder at a water-to-gypsum ratio of about 0.6 leads to microstructural changes: a polymer phase forms between the crystals of calcium sulfate dihydrate, which increases flexural strength, improves tensile behavior and reduces capillary water absorption, while simultaneously somewhat increasing the setting time and making the mixture more workable for complex sculptural modelling (Gomes et al., 2019).

Organo-mineral compositions developed for gypsums based on phosphogypsum waste show that the combined introduction of organic and inorganic additives enables simultaneous increases in strength and substantial reductions in mechanical performance loss after water saturation, which is critical for reliefs in zones of variable humidity (Wang et al., 2025). A distinct line of development involves the use of polysiloxanes and other hydrophobizing polymers: studies of macro-defect-free and bulk hydrophobic gypsum stones demonstrate that the formation of a hydrophobic layer on the pore surfaces and within the pore space sharply reduces the rate of water ingress and increases the durability of the material under cyclic wetting and drying (Zhu et al., 2024).

On another front, lightweight and mineral fillers address the task of reducing density without a drastic loss of strength: glass and vitrified microspheres, as well as porous aluminosilicate particles, make it possible to obtain compositions with a density on the order of 1000 kg/m^3 and a compressive strength of about 14–15 MPa, which significantly reduces the mass of finished elements while preserving load-bearing capacity (Petropavlovskii et al., 2025). Studies of gypsum boards with the clay mineral palygorskite and a small amount of glass fiber show a density reduction from approximately 1059 to 795 kg/m^3 when up to 30 % mineral filler is introduced, i.e., a mass decrease by almost one quarter, which is particularly important for extended panels and cantilevered sections (Wang et al., 2023). Similarly, the use of porous organic fillers (wood flour, rice husk, bamboo powder) provides a pronounced decrease in density and simultaneous modification of thermal and fire-resistance characteristics, thereby broadening the range of artistic and structural solutions (Anjum et al., 2025).

Another critical block of modifications concerns fiber reinforcement and rheology control, which together determine the deformation behavior and placeability of gypsum formulations. Glass, basalt, synthetic polymer and natural fibers introduced into the gypsum matrix form a dispersed reinforcement system that bears tensile stresses and limits crack opening; reviews of fiber-reinforced gypsum composites demonstrate a consistent increase in flexural strength and impact toughness with increasing fiber volume, and in several formulations a pseudo-plastic, strain-hardening tensile behavior is achieved, with strain values exceeding those of ordinary brittle gypsum by multiples (Jia et al., 2021).

For large-scale relief, this is fundamental: it becomes possible to design thin yet extended projecting elements and deep undercuts without the risk of instantaneous brittle failure along stress-concentration lines. Recent studies on the comprehensive strengthening of gypsums with glass fibers and the addition of carbon black or magnetite confirm that judiciously selected fiber systems and mineral modifiers simultaneously increase strength and control microcracking under service conditions (Yildizel et al., 2025). At the testing and forming stages, the determining factor is the set of chemical admixtures governing the fresh mix. Superplasticizers based on polycarboxylate ethers and naphthalene sulfonate resins adsorb onto the surface of calcium sulfate hemihydrate crystals, reducing water demand while maintaining or even increasing workability, resulting in a denser stone structure and higher compressive and flexural strength. Set retarders based on organic acids and their salts in small dosages (tenths of a percent of binder mass), enabling precise adjustment of initial setting time over a wide range, which is essential when modelling large-scale reliefs and working in situ. In contrast, accelerators provide rapid early strength development for removable molds and fast-track installation. Hydrophobizing admixtures, including those based on modified polysiloxanes, create a water-repellent phase within the pores and on the surface, reducing water absorption and capillary uptake without completely blocking vapor permeability, which is especially valuable for wall reliefs under demanding climatic conditions (Ren et al., 2025).

In the practical work of the artist and technologist, these modification groups are rarely employed in isolation; instead, complex systems emerge in which the polymer phase, mineral fillers, fibers, and chemical admixtures are selected as an integrated tool for a specific artistic task and service environment. Experimental developments for waste-based gypsums show that combinations of organic polymers, mineral additives, and contemporary superplasticizers can simultaneously increase strength, reduce water absorption, and assign the required working time to the mix, adapting it either to thin casting in closed molds or to multihour hand modelling of relief on the substrate (Wang et al., 2025). Lightweight and ultra-lightweight fillers, when combined with fiber reinforcement, enable the production of large-format panels with reduced mass and controlled flexural stiffness, suitable for fastening to light frames or suspended systems without risking overloading the substrate (Petropavlovskii et al., 2025). As a result, at the level of monumental and decorative art technology, gypsum mixtures are transformed from a single traditional material into an entire family of controllable composites: for some tasks the priority is extreme detail reproduction and whiteness at moderate strength; for others it is crack resistance and impact toughness in a complex spatial configuration; for still others it is minimal weight and enhanced moisture resistance. In all these cases, it is precisely the considered combination of polymer, mineral, fibrous, and chemical modifiers that defines the property spectrum previously unattainable for unmodified gypsum compositions. The main types of modifications of gypsum mixtures and their influence on the properties of the material are shown in Figure 1.

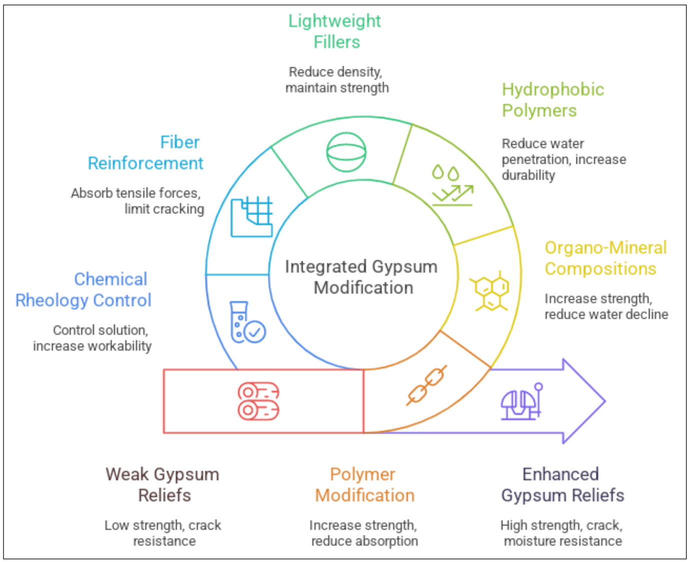

Fig. 1. Types of modifications of gypsum mixtures and their influence on the properties of the material

In the context of modified gypsum formulations, the choice of material for a bas-relief becomes, for the artist, a stepwise technological decision. For residential interiors, the usual preference is for a more plastic and compliant mixture with a gentle strength gain, allowing correction of form, smoothing of transitions, and subtle modelling under relatively benign service conditions. In public spaces, especially those with intense foot traffic, the priority shifts toward increased resistance to impact, abrasion, and localized loads, and thus a denser gypsum structure is used, reinforced with a polymer phase, fillers, and fibers. In dry environments, the criteria are shape stability, whiteness, and detailing. In wet interiors, the most important criteria are low water absorption rate, moisture resistance, and adhesion to ground coat and substrate. On the other hand, a wall formulation must be heavy and rigid enough to be applied to a vertical surface without sloughing off. Ceilings and heavily cantilevered structures need a lightweight, thixotropic material that will not flow under its own weight.

This is best achieved by first mixing the dry ingredients to a homogeneous mixture, then adding water and allowing it to soak for a short time, before mixing the mixture at an intermediate speed without excessive whipping. Excessively vigorous mechanical action leads to excessive air entrainment and segregation; therefore, even mixing cycles are preferable, with periodic cleaning of the vessel walls and bottom, and, where necessary, light vibration or rolling with a spatula to expel large air voids without destroying the structural framework of the future stone.

The technology of building relief with modified gypsum is generally structured as the staging of successive layers, each performing a specific function. The base layer forms the adhesive bond with the substrate and defines the overall geometry; accordingly, it is made stiffer, with moderate workability, and is applied with thorough pressing into the substrate and light scoring to provide mechanical interlock for subsequent layers. The sculptural layer is responsible for volume and plasticity: controlled plasticity and the capacity of the mixture to retain shape without sagging are essential here, enabling incremental build-up of protrusions and development of large and medium forms, combining in situ modelling with localized casting of fragments in molds. The finishing layer is typically thinner and more homogeneous; it is used to refine planes, soften transitions, create a lively texture, and prepare the surface for subsequent finishing.

When working on a large bas-relief, the artist conceptually operates with the notion of the window of mix life: the first minutes are used for placement and rough shaping; this is followed by a stage of plastic equilibrium, when the material already holds its form but still allows cutting, pulling, pressing and hatching; then comes the risk zone, when accelerated strength gain begins and any coarse intervention provokes tearing and delamination. By controlling this window through admixture dosing and thermo-hygrometric conditions, the practitioner can adapt the material to a personal working rhythm.

Hardening and drying demand no less discipline than modelling: overly rapid drying of thin elements leads to shrinkage gradients, interlayer cracking and debonding, whereas excessive humidity and lack of ventilation provoke creep, crushing of fine details and uneven lightening of the surface. Consequently, large reliefs are dried in stages, avoiding direct heating and drafts, and transitions between layers are carried out only after the previous layer has gained sufficient strength but has not yet become an inert, poorly bondable substrate. As a result, the technological culture of working with modified gypsum becomes for the artist as important a tool as drawing and composition, enabling the realization of complex spatial concepts without critical material defects. The main stages of a bas-relief artist's work with modified gypsum are shown in Figure 2.

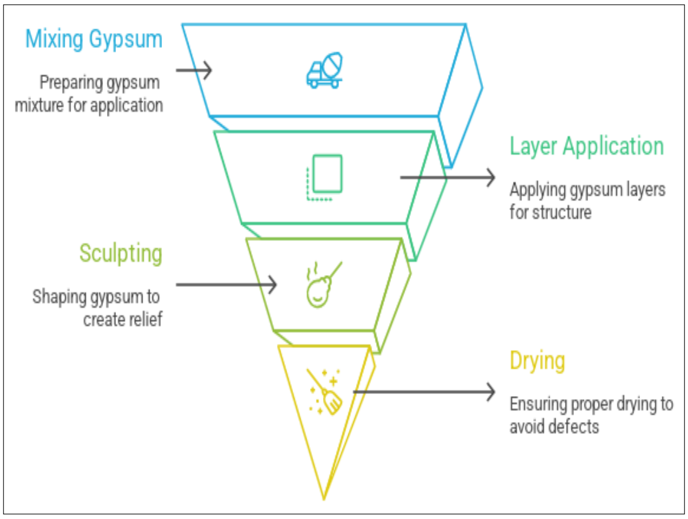

Fig. 2. The main stages of a bas-relief artist's work with modified plaster

The author's approach to working with a modified gypsum mixture in creating a volumetric bas-relief begins with a careful reading of the space and its translation into a set of specific artistic and performance requirements. The room is considered through the lens of its function, intensity of use, character of human movement, expected humidity and temperature fluctuations; it is taken into account from what distance and at what angles the viewer will perceive the relief, how natural and artificial light fall on it, and to what extent fragile projecting elements are permissible. From this emerges an understanding of the acceptable mass of the structure, the limiting thickness of the finishing layer, possible points of support and anchoring, the required durability, and maintainability.

The next step is to select the type of gypsum binder, the modification and reinforcement system, and specify the target density and plasticity of the mixture, as well as the balance between stiffness and compliance under the tool. At the stage of material exploration, the artist prepares test samples and small fragments of relief on an actual or simulated substrate, examining how the formulation behaves during placement, how much time remains for free modelling, when the optimal plasticity window for fine modelling occurs, and how the mix responds to different types of tool movement. In parallel, shrinkage, propensity for microcracking, and changes in shade and texture during drying are monitored; water content, the ratio of modifying admixtures, and the nature of fiber and structural reinforcement are adjusted as necessary so that the material becomes an organic extension of the author's manner rather than an external constraint.

Once the composition and its behavior are understood, attention shifts to the substrate and the process of form generation. The surface is cleaned, reinforced, and primed where necessary; the principal axes, nodes, and masses of the future composition are marked out, and embedded parts and frames are installed in zones of anticipated maximum loads and cantilevers. An adhesion layer with pronounced microrelief is applied to the prepared substrate, tying the structure to the modified gypsum. Next comes the stage of basic volume formation, when large masses, force geometry, hidden ribs, and masks that redistribute loads and account for inevitable shrinkage are set by broad movements. Work is carried out with a thickness margin, leaving material for subsequent carving and cutting instead of immediately striving for the final silhouette.

Sculptural elaboration unfolds in the interval when the mixture already holds the prescribed form but remains responsive to subtle interventions: at this time, proportions are refined, the pattern of light and shadow is constructed, secondary and tertiary masses are developed, and the transition from rough modelling to nuanced plasticity is implemented. At the detailing stage, the author often switches to a finer-grained, more plastic but compatible formulation, with which joints between portions of material are softened, textural effects are introduced and key contours are emphasized; not only traditional sculptural tools are used, but also brushes, fabrics and sponges, enabling the transformation of crystallization texture and traces of mixing into a deliberate artistic language.

The final part of the algorithm involves controlled hardening, finishing, and preparing the relief for service. The volume is protected from high temperatures and humidity fluctuations, direct airflow, and local overheating; special attention is paid to transitions from massive sections to thin petals and contours, where differences in drying rates may induce stresses and cracking. Vulnerable projecting elements are temporarily supported, if necessary, until sufficient strength has been reached; the uniformity of drying and absence of debonding are monitored visually and tactually. After structural stabilization, sanding and local carving are performed; accidental technological defects are removed; a priming system is selected to equalize absorbency and consolidate the surface; and then the chosen range of coatings and patinas is applied, constructing a dialogue between color and light–shadow.

In the final phase, a thorough inspection of fasteners, joints, and edge zones is carried out; the structural scheme and materials used are documented; photographic records are made from different viewpoints and lighting conditions; and maintenance recommendations are drafted, including permissible cleaning methods, limits on mechanical actions, preferred humidity regime, and frequency of preventative inspections. The algorithm's architecture is shown in Figure 3.

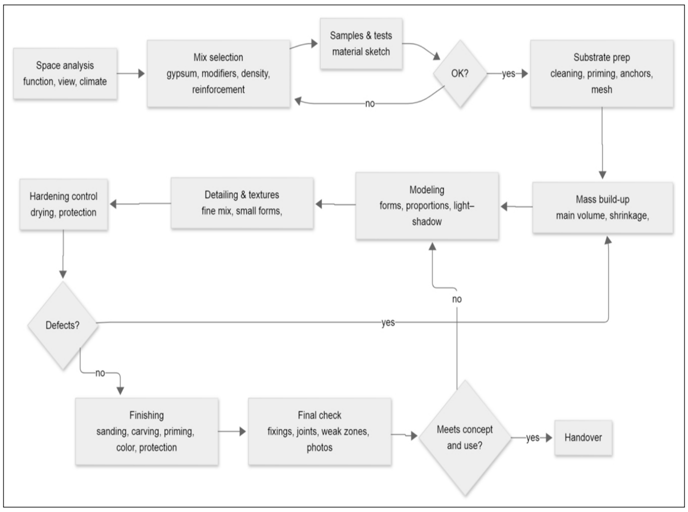

Fig. 3. The author's algorithm for working with a modified gypsum mixture when creating a 3D bas-relief

Thus, creative intent and technological discipline are integrated into a single sequence of steps, in which each stage of preparation, modelling, hardening, and finishing of the modified gypsum is pre-aligned with the bas-relief's future life in a specific architectural space.

CONCLUSION

Based on the material considered, the centuries-old tradition of using gypsum in architecture and decorative art has reached the threshold of its classical capabilities. A porous structure with active capillary water absorption, solubility under prolonged moisture exposure, brittle fracture behavior, and a short setting working window becomes critical when creating large-format, strongly cantilevered reliefs under demanding service conditions. This constellation of limitations predetermines the transition from ordinary building gypsum to modified compositions in which rheology, crystallization kinetics, density, and deformation behavior are deliberately designed for a specific monumental-decorative task.

It has been shown that polymer modifiers, light and functional mineral and organic fillers, fiber reinforcement, and chemical admixtures collectively form a new class of controllable gypsum composites. The polymer phase increases flexural strength, crack resistance, and moisture resistance; hydrophobizing agents impart bulk hydrophobicity; and organomineral systems based on industrial by-products reduce sensitivity to water saturation. Lightweight fillers reduce the mass of elements while maintaining load-bearing capacity; dispersed fibers control microcracking and flexural behavior; and superplasticizers, set retarders, and accelerators provide the required mix-life window and pore-structure configuration. As a result, the same base mineral is transformed into an entire family of materials, from plastic, finely modelling systems for dry interiors, to lightweight, impact-resistant, moisture-resistant composites for complex architectural situations.

A key result of the study is the author's algorithm for interaction between the bas-relief artist and the modified gypsum mixture, which turns material and technology selection into a sequential engineering-artistic solution. The initial step consists of reading the space and translating it into a set of performance and plastic requirements, followed by selection of binder type, modification, and reinforcement system, and a series of test samples and fragments that make it possible to reconcile the material with the author's working tempo and manner. The algorithm then encompasses substrate preparation and reinforcement, layered construction of the relief through adhesion, base, sculptural, and finishing layers with a controlled plasticity window, controlled hardening and staged drying, finishing, and formulation of an operational protocol. In this way, the proposed algorithm integrates creative intention and technological discipline into a unified action framework, in which modified gypsum serves not as a passive medium but as a pre-engineered carrier of durability, crack resistance, moisture resistance, and plasticity for the future bas-relief.

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