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GENERATIVE DECOMPOSITION OF HISTORICAL FORMS IN POSTMODERN ARCHITECTURE

GENERATYWNA DEKOMPOZYCJA FORM HISTORYCZNYCH W ARCHITEKTURZE PONOWOCZESNEJ

A b s t r a c t

In the pluralistic culture of postmodernity, the novelty of architecture is intertwined with the heritage of the past. The article provides a synthetic review of realisations and literature from 2015 to 2025, in which generative algorithms are used to decompose and recontextualise Gothic, Baroque, and Classical motifs. Three trends were identified: "algorithmic baroque", combining digital ornamentation with solid expression; "biomimetic networks", translating vaults into lightweight truss shells; and "parametric classicism", where modular orders adapt to changing conditions. The analysis reveals that generative decomposition reduces material and energy consumption while maintaining recognisable forms through shape optimisation and the use of hybrid composites. The conclusions organise the definition of the phenomenon and demonstrate that a critical dialogue with history, guided by algorithmic tools, can be a catalyst for responsible innovation. It also signals knowledge gaps about the influence of environment and culture on the further evolution of approaches.

Keywords: generative decomposition, parametrics, heritage, baroque, gothic, classicism, biomimetics, material optimisation

S t r e s z c z e n i e

W pluralistycznej kulturze ponowoczesności nowość architektury splata się z dziedzictwem przeszłości. Artykuł syntetycznie przegląda realizacje i literaturę z lat 2015–2025, w których generatywne algorytmy służą dekompozycji oraz rekontekstualizacji motywów gotyku, baroku i klasycyzmu. Wyróżniono trzy nurty: „algorytmiczny barok" łączący cyfrową ornamentykę z ekspresją bryły; „biomimetyczne sieci" przekładające sklepienia na lekkie powłoki kratownicowe; oraz „parametryczny klasycyzm", gdzie modułowe porządki adaptują się do zmiennych warunków. Analiza pokazuje, że generatywna dekompozycja pozwala ograniczyć materiał i energię, zachowując rozpoznawalność form dzięki optymalizacji kształtu i hybrydowym kompozytom. Wnioski porządkują definicję zjawiska i dowodzą, że krytyczny dialog z historią, prowadzony przy pomocy narzędzi algorytmicznych, może być katalizatorem odpowiedzialnej innowacji. Sygnalizuje też braki wiedzy o wpływie środowiska i kultury na dalszą ewolucję podejść.

Słowa kluczowe: generatywna dekompozycja, parametryka, dziedzictwo, barok, gotyk, klasycyzm, biomimetyka, optymalizacja materiałowa

1. INTRODUCTION

New computational tools have made it possible to re-evaluate the question of the "originality" of architecture, shifting the focus away from a radical break with tradition. In the second digital turn, as Mario Carpo calls it, the algorithm treats history not as a storehouse of ready-made motifs, but as a source of rules that can be reinterpreted under the conditions of today's social and energetic needs[1]. Instead of copying details, designers extract relationships of proportion, rhythm, and curve, and then iterate them as quickly and precisely as operations in software engineering.

In this context, generative decomposition stands out as a method that first decomposes motifs that have existed in architecture for centuries into sets of parameters. It only then synthesises them with structural, climatic, and material criteria in mind. This procedure differs from classical "parametric design" in that it defines a hierarchy of inter-dependent generators (geometry, structure, microclimate, prefabrication), so that each correction propagates through the entire design model. Within this trend, generative decomposition stands out: a process of algorithmic decomposition drawn from architectural theory, which is then re-synthesised, taking into account structural, material, and energy criteria. New incarnations of historic forms retain their recognisability, but are slimmed down, optimised, and adapted to the requirements of sustainable construction.

This article aims to explore this method between 2015 and 2025, sorting out three dominant adaptations: algorithmic baroque, biomimetic networks, and parametric classicism. Analysis of the realisations shows that over the last decade, the centre of gravity has shifted from aesthetic complexity towards performativity: complex geometries are now justified by reductions in mass, energy, or CO_2 emissions. In the discussion, we consider both international literature and Polish studies to outline local variations of a global phenomenon and identify research gaps that may shape the agenda of subsequent analyses.

2. LITERATURE REVIEW

Mario Carpo notes that in the so-called "second digital turn", designers are using algorithms not only to produce forms, but also to understand the cultural processes that produce these forms[2]. In other words, digital architecture has ceased to be a technological "demonstration of power" – it is becoming a method of formal archaeology. In Poland, this direction was described by Juchnevič, Radziszewski et al. in their article *Parametric Architecture* (2016), emphasising that visual programming (Grasshopper, Dynamo) opens the way to the 'parameterisation of compositional rules' taken from history[3]. Rather than copying a detail,

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[1] M. Carpo, *The second digital turn. Design beyond intelligence*, The MIT Press, Cambridge 2017. DOI: 10.7551/mitpress/9976.001.0001.

[2] M. Carpo, *A very short, but hopefully believable history of the digital turn in architecture* [in:] Mario Carpo, 2020, https://mariocarpo.com/essays/a-very-short-story-of-the-digital-turn-in-architecture?utm (access: 20.07.2025).

[3] E. Marcinowska et al., *Projektowanie zasad i algorytmu kształtowania formy przestrzennej* [in:] ResearchGate, January 2016, https://www.researchgate.net/publication/289504963_Architektura_parametryczna_Parametric_Architecture (access: 20.07.2025).

the idea is to extract relationships – proportions, rhythms, and curves – which can then be re-variantised by an algorithm.

Giedrowicz's analysis well illustrates this evolution: the first parametric realisations exuded complexity (e.g., the Heydar Aliyev Centre), while more recent practices shift the emphasis from aesthetics to performativity, reducing primary energy, rationalising A/V, or optimising radiation[4]. Similar conclusions are drawn from Płoszaj-Mazurek's research on parametric footprint optimisation (2019), in which genetic algorithms select lump and insulation variants to minimise CO_2 emissions[5]. This approach redefines traditional styles: baroque dynamics can now be derived from the analysis of airflows, and classical harmony from the balance of energy.

3. CONTEMPORARY TRENDS IN PARAMETRIC ARCHITECTURE

The literature today proposes three distinctly different ways of thinking about parametric architecture. Their names – algorithmic baroque, biomimetic networks, and parametric classicism – are not a memorable list of labels, but rather shorthand for three distinct strategies for shaping form, construction logic, and design narrative. The distinction emerged when the research community began to seek more precise descriptions than the generic notion of "parametricism" introduced by Patrik Schumacher, which captures only the mere fact of parametric variation and not its qualitative consequences[6].

Algorithmic Baroque emerged from the enthusiasm of the 2000s and 2010s, when NURBS algorithms and Computational Fluid Dynamics (CFD) tools enabled the development of sculpturally fluid, multi-layered surfaces. The curators of the 2013 New York exhibition "Out of Hand: Materializing the Postdigital" described this aesthetic as a "post digital style: a kind of algorithmic baroque" – a wealth of folds, perforations, and non-repetitive ornamentation[7]. Its pioneering projects include the Heydar Aliyev Center in Baku, whose load-bearing structure is entirely controlled by the parameters of the curvature rays and coupled to a structural model, and the interior of the Elbphilharmonie in Hamburg with 10,000 unique acoustic panels whose relief was calculated to balance the reverberation time (Ill. 1). In Poland, the closest to this group is the Museum of Fire in Żory, where parametric "wings" made of copper sheeting were created by algorithmically compacting planes over existing underground infrastructure. The foundation of the algorithmic baroque is the aesthetics of complexity; structural issues are captured after the fact, fitting the form that emerged from the code.

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4 M. Giedrowicz, Zastosowanie projektowania parametrycznego dla architektury energooszczędnej – studium przypadku, "Buidler" 2023, no. 10, pp. 55–61. DOI: 10.5604/01.3001.0053.8654.

5 M. Płoszaj-Mazurek, Parametryczna optymalizacja śladu węglowego budynków [in:] B. Gronostajska (ed.), *Miasto dla ludzi – miasto jutra*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2019, pp. 303–315.

6 P. Schumacher, *Parametricism: A new global style for architecture and urban design*, "Architectural Design" 2009, no. 4, pp. 14–23. DOI: 10.1002/ad.912.

7 J. Nechvatal, *Review of Philippe Parreno exposition Anywhere, Anywhere, Out Of The World (with reflections on a post-relational art)* [in:] Hyper-Noise Aesthetics, 26.10.2013, https://josephnechvatal.wordpress.com/2013/10/26/review-of-philippe-parreno-exposition-anywhere-anywhere-out-of-the-world-with-reflections-on-a-post-relational-art/?utm_source=chatgpt.com (access: 20.07.2025).

Ill. 1. Elbphilharmonie in Hamburg, photo by Aneta Stefańska

Biomimetic networks take the opposite starting point: their form is determined by the optimisation of flows, loads, and energy exchange inspired by the structure of bone, plant tissue, or vascular systems. Under digital conditions, this continues Frei Otto's intuitions, but with the precision of topological and evolutionary analysis. Beijing National Aquatics Center ("Water Cube") used Weaire Phelan's foam model to create a rigid, three-dimensional grate with minimal mass. Later experiments, such as the ICD/ITKE pavilions in Stuttgart, have developed fibrous shells coded in reference to spider and insect carapaces. In the realm of façades, research on cooling imitating elephant skin shows how evolutionary algorithms turn climate data into micro-panels. Polish work tends to focus on theory: Onyszkiewicz systematises the criteria of biomimetics in architecture and emphasises the importance of networked material reduction[8]. In this strand, the formal decision is a product of performance analysis; beauty comes from the consistency of function, not from a redundant gesture.

[8] J. Onyszkiewicz, *Elementy biomimetyki w projektowaniu architektury w środowisku zrównoważonym. Ewolucja i interpretacja bioniki na przykładzie polskich i zagranicznych konkursów architektonicznych [Elements of biomimetics in designing architecture in a sustainable environment. Evolution*

Parametric classicism refers to the tradition of proportion and order, but reinterprets it with variables that allow classical rules to be scaled, bent, or locally differentiated. Francesco Bedeschi has shown how digital models treat Vitruvian canons as a set of editable algorithms – this is “classicism in the form of a parametric constructor”[9]. Michael Hansmeyer goes the furthest, transforming columnar order into almost biological, fractal structures; each of his “Subdivided Columns” is a variation arising from the same loop of subdivisions. In Poland, these ideas are permeating conservation research. The Romaniak-Kulig-Filipowski team has developed a parametric model of Late Gothic vaults, enabling the dynamic recreation of the proportions of the historic fabric[10]. Parametric classicism values consistency and legibility; the algorithm here serves discipline rather than expression.

The main differences between the three currents stem from the hierarchy of criteria that the computational model inscribes. Algorithmic Baroque prioritises visual complexity, biomimetic networks prioritise material and environmental performance, while parametric classicism prioritises relationships of proportion and spatial order. This results in a different morphology, construction, and perceived mood of objects, ranging from dramatic, fluid sculptures to “living” networked bodies and to to disciplined transformations of the archetypal. Understanding these divergent logics is facilitated by consciously combining a conceptual layer with a practical digital workshop. Choosing one of the doctrines is not a matter of fashion, but of clearly defining which parameters – expression, performance, or order – are to guide the structural and formal narrative of the designed object.

4. GENERATIVE DECOMPOSITION METHODOLOGY

Generative decomposition methodology (GDM) describes a process in which a complex spatial and structural programme is broken down into a series of inter-dependent generators – algorithmic modules responsible, in turn, for geometry, structure, microclimate, or assembly logistics. Each module operates on its own set of parameters, passing the results up the hierarchy. In this way, any correction propagates through the entire model, allowing its effects on the forms of finding and structural analysis to be assessed immediately. Such a structured process organises what the literature often categorises under the general heading of “generative design” and completes the taxonomy of concepts (parametric, algorithmic, and generative) with a precise sequence of steps[11].

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and interpretation of bionics by the example of domestic and foreign architectural competitions], PhD thesis, Politechnika Wrocławska. Wydział Architektury, Wrocław 2019, https://www.dbc.wroc.pl/Content/72670/Onyszkiewicz_Elementy_biomimetyki.pdf (access: 20.07.2025).

9 F. Bedeschi, *Classical architecture as parametric construct* [in:] F. Jacobus et al., *Architectonics and parametric thinking*, Routlendge, New York 2023, https://doi.org/10.4324/9781003252634-7 (access: 20.07.2025).

10 K. Romaniak, A. Kulig, S. Filipowski, *Parametric modeling of the late Gothic vault: a case study of St. Zygmunt Church in Szydłowiec (Poland)*, “Digital Applications in Archaeology and Cultural Heritage” 2025, vol. 37, art. no. e00426, https://doi.org/10.1016/j.daach.2025.e00426 (access: 20.07.2025).

11 I. Caetano, L. Santos, A. Leitão, *Computational design in architecture: Defining parametric, generative, and algorithmic design*, “Frontiers of Architectural Research” 2020, no. 2, pp. 287–300, https://doi.org/10.1016/j.foar.2019.12.008 (access: 20.07.2025).

The origins of GMD lead to two parallel currents. On the one side stand Christopher Alexander's "generative codes"[12], in which the vitality of a form is supposed to be determined not by the shape itself, but by the sequence of actions – the so-called unfolding sequence – ensuring that space, material, and user form a coherent system. On the other lies research into the decomposition of a design problem, from the dependency matrix in *Notes on the Synthesis of Form*[13] to today's lectures on computational design, which combine the dissection of a problem with the logic of a code. In the Polish literature, this theme recurs as a hierarchical analysis of the problem and is regarded as a condition for sound design synthesis.

A practical breakthrough has come from tools like Bentley GenerativeComponents, where each model object is also a node in a network of dependencies; the software itself is described as a "tool-making application", emphasising the ability to build one's generators. In a model of the roof of the Francis Crick Institute in London, the PLP team analysed more than a hundred variations in the curvature and division of the louvre, with each iteration resulting from the manipulation of several parameters without the need for manual rebuilding of the detail.

In recent research publications, generative decomposition takes the form of a Function-Behaviour-Structure (FBS) workflow. The algorithm divides the task into functional subtasks, defines behavioural metrics (e.g. load paths, energy balance), and only in the third step synthesises the geometry; each step can be handled by a separate optimisation engine or AI model. Thus, decomposition becomes both a protocol for inter-organisational communication and a scaffold for generative operations.

The most crucial difference between GDM and classic "algorithmic baroque" is that the decomposition logic is created before the first line of code: the designer decides which aspects will be generated and which merely inherit higher-level parameters. In this way, the entire process remains transparent, and each module can be tested and replaced without affecting the overall system. GDM brings architecture closer to software engineering: the building becomes a system of co-operating packages that are refactored iteratively until expression and design logic reach a common equilibrium point.

Table. 1. The processes presented can be summarised in four basic phases.

Phase	Actions	Tools	Results
Historic Analysis	Extraction of compositional rules (axis rhythm, arch profile, classical module)	photogrammetry, Rhinoceros + Grasshopper	Set of basic parameters
Parametrisation	Transcription of rules into a script (e.g. explicit history)	Python, C# nodes	Algorithm generating variants
Performance simulation	Structural assessment, energy assessment, LCA	Karamba3D, Ladybug Tools	Fitness data for the optimiser
Design synthesis	Choosing the "best balance" option between form and performance	genetic algorithms, machine learning	BIM model ready for prefabrication

[12] C. Alexander et al., Generative codes. The path to building welcoming, beautiful, sustainable, version 17, DRAFT, Centre for Environmental Structure, Berkeley, November 2005, https://www.wiki.coevolving.com/generative-code.html (access: 20.07.2025).

[13] C. Alexander, *Notes on the synthesis of from*, Harvard University Press, Cambridge 1973.

5. A SYNTHESIS OF HISTORICAL AND POST-MODERN FORMS

By incorporating considerations of generative decomposition into the "Architecture and History" strand, we shift the emphasis from the fetishisation of technology to the continuity of architectural thought. The study then becomes another facet of the age-old debate about the relationship between form and memory: digital algorithms are not the exception to the rule, but another tool through which architecture interprets its heritage. This approach enables the juxtaposition of analyses of the parametric code with classical studies of proportion or structure, demonstrating that the variable characterising the curvature of a roof has a function analogous to the old canonical modules and measures. The difference lies only in the scale of precision and the speed of iteration, not in the logic of referencing earlier schemes.

The novelty of the post-digital age thus stems from the possibility of recombining traditional motifs, rather than breaking with them. Instead, the parameters here serve as enzymes to help synthesise between a layer of historical patterns and the requirements of contemporary functional and environmental programmes. When an algorithm transforms a column into an evolved morphology reminiscent of a biological structure, it still operates on the canon of the stem-head division; it just moves it into another dimension of complexity. Thus, the post-digital architecture does not so much cancel the memory of the forms as extend their "genetic code", allowing further evolution without loss of genealogy.

6. HYBRID MANUFACTURING AND PREFABRICATION TECHNOLOGIES

Digital design today does not affect aesthetics on its own; its effects are materialised by new production lines whose logic corresponds to the algorithmic generators described in the generative decomposition methodology. Two technologies are leading the way: the robotic winding of coreless fibres and the large-scale printing of concrete and composites. What they have in common is a move away from the forms associated with lost formwork to the additive construction of a component layer by layer, exactly where structural analysis indicates a need for material.

In robotic fabrication, cores and harmful moulds are replaced by the robot trajectory itself. The pioneering ICD/ITKE Pavilion in Stuttgart, culminating in the BUGA Fibre Pavilion, was created by coreless filament winding: a KUKA arm wraps carbon and glass fibres between two rotating shapers, and the shape emerges solely from the mutual stiffening of the threads, eliminating material waste. The 23m-span structure weighs just 7.6kg/m^2, about five times less than a steel structure of comparable load-bearing capacity. Winding paths are generated directly from the parametric model; each of the 60 segments receives its own G-code file, so that geometry, fibre density, and orientation relative to principal stresses are controlled by the same script that is responsible for structural validation. The integration of the KR QUANTEC robot into the design engine means that an update of even a single parameter triggers an immediate correction of the trajectory and recalculation of material consumption. Within the MGD, the "fibre structure" module thus acts simultaneously as a mould generator and CAM interface, with communication between them limited to the exchange of force vectors and nozzle-tip coordinates.

Ill. 2. P. Pintos, *BUGA Fibre Pavilion / ICD/ITKE University of Stuttgart* [in:] ArchDaily, 9.05.2019, https://www.archdaily.com/916650/buga-fibre-pavilion-icd-itke-university-of-stuttgart (access: 28.07.2025)

3D printing in concrete integrates similar principles on a larger scale, suitable for building volumes. A record-breaking villa in Dubai, featuring 300m² of walls printed in a single four-metre strip without robotic repositioning, demonstrates that additive prefabrication is beginning to compete with traditional reinforced-concrete fabrication, while also aligning with a strategy to reduce greenhouse-gas emissions. The initial limitations of the technology, such as interlayer adhesion and surface roughness, are now being addressed through the use of automated quality control. A depth camera, lidar, and photogrammetry are used to verify the geometry as it is printed in an online loop, so that the layer deviation can return to the trajectory-generating module after only a few seconds.

In the generative decomposition model, both processes appear as independent technological generators. The script defining the thickness of the concrete layer or the number of fibre rotations becomes equivalent to the climatic or functional module. In this way, the flow of information is bi-directional: the load analysis updates the winding density, and the registered deviation of the printer nozzle can trigger a local adjustment of the construction mesh. Such a data chain not only reduces the risk of assembly error, but also paves the way for the introduction of responsive materials in the building life cycle – from fibrous coatings with integrated photovoltaics to concrete walls capable of self-healing. Hybrid prefabrication thus ceases to be the final stage. It becomes an integral part of the design process, where geometry, structure, and manufacturing technology collaborate to shape the design in real time.

7. PROSPECTS FOR FUTURE RESEARCH

The coming years will force the coupling of generative models with predictive climate simulations. In the Porto Alegre museum project, the entire assumption was reworked to account for the increase in tropical nights, shifting the optimal angle of the shading wings by six degrees and adjusting the proportion of glazing by almost ten percentage points. Such operations require dynamic linking of the form finder solver with IPCC databases; the new generation of scenarios, REPs, is even designed to be saved in JSON schema and directly loaded into Grasshopper scripts. It therefore becomes necessary to develop an interface standard between energy models and geometry generators, where the result of one simulation immediately becomes a parameter of the next, creating a design-prognosis-correction loop.

In parallel, the migration of generative logic to large language models continues. ArchGPT prototypes can already extract canonical composition rules from an ancient treatise, write them as a dependency tree, and then produce Python code that directs a topological solver[14]. The Boston and Shenzhen labs utilise this capability as a pillar of "dialogic BIM", in which the designer formulates the intention in a natural sentence, and the LLM proposes a series of model mutations and calculates the structural effects. From the perspective of the generative decomposition methodology, this means that the textual layer – function description, historical citation, and planning assumptions – can become an equal module in the hierarchy of generators.

The third axis of development is hybrid materials, in which the structure itself acts as an energy or sensory infrastructure. Photovoltaic fabric prototypes, such as Suntex, combine thin-film CIGS cells with carbon fibres so that the pavilion membrane acts simultaneously as a structural sail and a 60 W/m^2 generator[15]. Research on dynamic dvPVBE facades shows that algorithm-controlled weaving patterns can increase energy yields by more than 15% relative to classical glass-glass modules, while maintaining a 25% translucency. When such solutions are integrated with the MGD model, the fabric parameters – elastic modulus, power density, and translucency gradient – become variables that circulate between the form generator, structural analysis, and daylighting simulation. Architecture practically acquires a "skin" capable of photosynthesis and self-diagnosis, and the designer's task is no longer so much to select the material as to orchestrate its multifunctional properties throughout the building's life-cycle.

What emerges, then, is a picture of a post-digital practice in which algorithms, climate scenarios, and reactive materials form a shared ecosystem of data. Future research will grapple not with how to generate a form, but how to synchronise its evolution with the parallel evolving conditions of the environment, energy, and social normatives.

8. SUMMARY

This paper demonstrates that generative algorithms are becoming a tool for a critical archaeology of forms today: instead of cutting themselves off from their heritage, they decompose Gothic, Baroque, and Classicism into parameters, which they then recombine in terms of structural, energetic, and material requirements. An analysis of three contemporary currents – the expressive "algorithmic baroque", the efficient "biomimetic networks", and the disciplinary "parametric classicism" – reveals that the character of the work is determined not by the digital tool itself, but by the priorities inscribed in the computational model: visual complexity, minimisation of mass or legibility of proportion, respectively. The generative decomposition methodology organises these priorities by dividing the project into a hierarchy

[14] J. Zhang et al., *ArchGPT: harnessing large language models for supporting renovation and conservation of traditional architectural heritage*, "Heritage Science" 2024, no. 12, art. no. 220, https://doi.org/10.1186/s40494-024-01334-x (access: 20.07.2025).

[15] P. Dongen et al., *Suntex: weaving solar energy into building skin*, "Journal of Facade Design and Engineering" 2022, no. 2, pp. 141–160, https://jfde.eu/index.php/jfde/article/view/244 (access: 20.07.2025).

of inter-dependent generators (geometry, structure, microclimate, and prefabrication), so that each correction propagates through the entire research cycle – from photogrammetric extraction of the detail to the BIM-ready variant for production.

The implementation of this methodology is possible because manufacturing lines, including robotic filament winding and 3D printing in concrete, can today reproduce locally varying geometries with the accuracy of a single nozzle path, integrating the design with CAM code and quality control in an online loop. The result is an architecture that reduces the carbon footprint, weighs less than analogous steel systems, yet retains cultural recognition through a "parametric memory gene". Prospects for further research indicate three dominants: coupling of generators.

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