

ANALYSIS OF THE GEOMETRY AND COMPOSITION OF THE MAIN FACADE OF INTERWAR ARCHITECTURE, USING THE JAROŇ VILLA IN BRATISLAVA AS AN EXAMPLE

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Abstract

The perception of interwar residential architecture in Slovakia, particularly among the lay public, reflects a significant lack of information and recognition of its architectural values. This limited understanding contributes to low social interest and negatively affects the current state of these works. Here, "interwar architecture" refers to buildings designed between 1918 and 1939. This article examines the architectural quality of family houses and villas in Bratislava, which reached an exceptional level during this period. We argue that, in the Slovak context, where radical spatial creation is largely absent, architectural value is concentrated in geometric and proportional order. We propose a methodology for geometric analysis of dominant facades, implemented in a digital BIM environment. The analysis progresses from the primary proportional framework through compositional nodes and rhythmic axes to a synthesis confronting facade geometry with internal spatial and structural logic. We examine harmony and timeless canons, including the golden ratio and root systems, replacing subjective description with precise data. The methodology will be tested on the former Bratislava villa Jaroň. The resulting objective framework may support understanding and conserving interwar architectural heritage, monument

restoration, and sensitive new design in historically valuable environments. It also establishes a transferable analytical framework for assessing architectural quality systematically, supporting more informed interpretation, documentation, and conservation of valuable residential works from the period within contemporary architectural practice and heritage.

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- detached family house

1 INTRODUCTION

In an historical context, architecture in a developed cultural society was perceived as the most complex of the creative expressions. It was not just a building, but a “mirror of the soul” (Ruskin, 1849) and a reflection of the taste of society, which it not only represented, but also shaped and improved. Since ancient times, an architectural work has been required to have absolute harmony between aesthetic and construction-technical aspects, and creators have been judged precisely by their ability to achieve this rare balance.

All socially important buildings of the past grew out of clear mathematical, harmonic and geometric principles, which were verified by generations. However, with the advent of the technological age, a large part of architectural production lost its former lofty status. In the 20th century, basic architectural questions began to be interpreted primarily by logic and analysis. The result of this approach was expected to be a rational, economically accessible, building enlivened by the individual aesthetic sense of the designer, a structure that would remain functional and at the same time, aesthetically valuable in the new industrial era.

The First World War brought about a radical change, which not only acted to reassessed social relations, but also accelerated the development of new procedures and materials in architecture. The German Bauhaus school (Droste, 2015), which gave rise to modern functionalist architecture, had an extraordinary influence on this development. Part of the theories of the architect Le Corbusier (1887–1965), as well as the founders of the Bauhaus, especially Walter Gropius (1883–1969), was the application of scientific rationalism to the creative process. Only an element that was considered scientific, logical, and therefore rational, could be applied to the design of the new architecture. In the Czechoslovak environment of the time, this trend was primarily

represented by Teige's doctrine of scientific architecture, which rejected architecture as art and defined it as a strictly scientific discipline (Halík, 2022). Therefore, all ornamental details were programmatically eliminated from the expression of buildings.

Architects sought new ways to visually express the structural design of a building and to project the layout of interior spaces onto a facade. The individualistic style of the master architects who shaped this movement in the 1920s and 1930s developed in an environment where harmony and proportion were still naturally respected. However, their followers often distanced themselves from this inner discipline, which led to conceptual sterility, a desire for eccentric originality, or self-serving innovation (Bangs, 2008).

The domestic architectural scene was undergoing intensive profiling during this period. The then Czechoslovakia achieved significant successes in the field of housing culture, as evidenced by numerous projects published in periodicals. Elegant residential neighbourhoods and villas, which became a part of almost every major city of the then state, are still evidence of the high level of production at that time. Although Slovak modernism as part of the then Czechoslovak architecture drew on radical world concepts, in the domestic environment we have rarely encountered their pure application. The absence of exact examples of strict *Raumplan* or *Plan Libre* in the Slovak context has led to a need to look for other methodological tools to evaluate the quality of this architecture. As architect Ladislav Beisetzer (1980) stated: *"An architectural work must spring from a permanent communal need; it must blend in with its surroundings if it is to be useful. Art in architecture is applied by respecting the laws of harmony, and in science by adhering to the laws of continuity. Architecture is the science of spaces and shapes."*

Our article follows on from the idea cited above and aims to precisely analyse the geometric essence of the facades of interwar villas in Slovakia. Geometry becomes a key analytical tool where spatial concepts take on hybrid forms. The term hybrid in the context of the domestic architectural scene of the interwar period denotes a specific local synthesis of traditional building practices and a new modern visual expression. Due to the limited technological and material base and a more conservative environment, radical spatial concepts (such as the strict Plan Libre or Raumplan) did not apply in our country. This modern concept was often applied to classic massive load-bearing systems. Through the analysis of proportional systems and mathematical relationships, we will try to reveal the “built-in” rules of harmony that make these works timeless and thus develop new and the exact criteria for their evaluation and the possible protection of relevant monuments.

2 DISCOVERING THE RELATIONSHIPS BETWEEN GEOMETRY AND ARCHITECTURE

Geometry in architecture has evolved from a symbolic order to a recognized aesthetic form. All the great eras of the past approached geometry in different ways, which significantly influenced the resulting architectural expression. In ancient Greece and Rome, geometry was understood from a deeply philosophical perspective based on the “cosmic order” (Plato, 2008; Vitruvius Pollio, 1979). During the Renaissance, it was viewed as a tool for achieving absolute beauty. This was a period in which geometry became strictly mathematical (e.g., works by Andrea Palladio, Leon Battista Alberti).

The Enlightenment marked a significant turning point for the technical aspects of architecture. This was particularly true in the 18th century, when Gaspard Monge scientifically formulated the method of descriptive geometry (Medek, 1962). In the 20th century, under the

influence of Purism and Functionalism, interest in geometry moved from the structure directly to the facade. Prominent architects of their time, e.g., Adolf Loos and Le Corbusier contributed to this development (Wittkower, 1949; Le Corbusier, 2005).

Contemporary architectural theory draws on a broad spectrum of geometric systems, they range from classical descriptive geometry, through non-Euclidean and fractal geometry, to contemporary parametric geometry. While today's shift toward digital tools based on parametric geometry makes it possible to create complex nonlinear forms, in order to understand the interwar period, it is essential to return to the logic of the drawing board, primarily because historical drawing techniques and descriptive geometry shaped the very way architects thought about buildings (Pérez-Gómez & Pelletier, 1997).

Theoretical research on geometry in architecture shows that the beauty of buildings is not accidental but is based on precise mathematical and geometric rules. The following authors and their works form a chronological chain from the discovery of universal canons to the current method of digital analysis, which we will implement and further develop in our work.

Jay Hambidge defined the concept of dynamic symmetry in 1920, which is based on the geometric growth of areas using square-root rectangles ($\sqrt{2}$, $\sqrt{3}$, $\sqrt{5}$) (1967). His contribution is important for our research from a technical point of view, because it provides instructions on how to derive the entire compositional network of a facade from a single square. Hambidge's method proves that modern facades have their own invisible skeleton, which we can decipher backwards. Matila Ghyka (1946), who worked at universities in the USA and Europe, scientifically substantiated the presence of the golden ratio ($\phi \approx 1.618$) in natural structures and in iconic works of history. In his work, he defines geometry as a universal language of harmony.

His claim that the aesthetic experience of architecture is directly linked to measurable mathematical proportions is important for our research.

Rudolf Wittkower proved that Renaissance buildings (especially those by Andrea Palladio) are built based on strict mathematical intervals (1949). In doing so, he refuted the idea of architecture as a purely intuitive art. His work confirms that the primary compositional order of a work is most legible on the main facade, which is also a basic assumption for our research. In 1947, Colin Rowe compared a Renaissance villa with a modern villa by Le Corbusier using geometric diagrams 1979. He found that although they used different materials, their mathematical basis and proportional grids are almost identical. This work has stimulated the search for classical canons of beauty in the architecture of interwar modernism.

In 1948, Le Corbusier introduced his own proportional system, Modulor, which combines human scale with the golden ratio (2004). Here, Le Corbusier defined mathematics as a tool for achieving order and purity. Modulor is proof that modern architects consciously work with numerical series, which we are trying to digitally verify and confirm in our work. Alojz Struhár represents a key methodological pillar in the Slovak professional context and a unique attempt at in-depth deciphering of the hidden geometric order that defines the architectural quality of works in a broad time spectrum from the Romanesque style to Classicism. In his work, Struhár proves that historical architecture in our territory was not the result of random aesthetics, but strictly followed predefined geometric canons based on the mathematical properties of the square, circle and triangle. He analysed in detail not only the application of the golden ratio ($\phi \approx 1.618$), but also root systems, especially $\sqrt{2}$ and $\sqrt{3}$, which, according to him, are the key to achieving the compositional balance and visual stability of facades (1977).

Peter Eisenman (2003) introduced the method of critical decomposition, where the facade is not perceived as an image, but as a record of geometric processes. This method allows the facade to be analytically decomposed into its basic elements. Eisenman confirms that these processes are most intensively recorded in the main facades of objects. Currently, research into the relationship between architecture and mathematics has mainly been conducted by Kim Williams (2020a, 2020b) and Kim Williams & Michael J. Ostwald (2015a, 2015b, 2019), whose works demonstrate that digital verification of proportions is a current scientific problem. Based on the above works, we can conclude that our research is part of a broader global trend of an exact analysis of architectural production.

3 METHODS

Previous scholarly reflection on domestic interwar architecture has relied heavily on visual judgment in assessing its aesthetic and harmonic qualities. For a long time, theoretical discourse has lacked an exact, quantifiable approach that would substantiate the architectural quality of these works with measurable data. As a result, the internal compositional logic of many significant structures remains largely misunderstood.

In Slovak academic circles, there has long been a lack of works addressing this topic, with the sole exception being that of Struhár (1977) which however, dealt exclusively with older architecture. Architecture from the first half of the 20th century has not received close attention in our country to date from the perspective of geometric analysis. Abroad, however, geometric analyses of the facades of interwar architecture have revealed the presence of these principles, as evidenced, for example, by the analysis of the main facade of the well-known Casa del Fascio building in Como, Italy (Eisenman, 2003). For our research, we can

formulate the hypothesis that such an exact analysis increases awareness of the quality of buildings. The absence of this awareness in our context leads, in extreme cases, to the complete destruction of architectural values, as evidenced, for example, by the demolition of a significant Bratislava building, Villa Jaroň (discussed below).

Based on these theoretical and methodological foundations, we formulated three main hypotheses for the purposes of the research:

- Hypothesis No. 1: **The presence and exactness of geometric order.** The architectural production of family houses and villas in Bratislava from the interwar period exhibits an exact geometric order, which, through clear proportional relationships, defines the resulting compositional outline of their dominant facades (street frontages).
- Hypothesis No. 2: **The universality of the geometric canon.** The application of geometric and harmonic principles on the facades of the structures under study is not a random phenomenon but represents a common and conscious canon of contemporary architectural creation. This system shows a high degree of consistency across different authors and stylistic trends, which confirms the existence of a unifying methodology in domestic architectural creation, the qualitative standards of which were formed primarily in the Bratislava environment and in other centres such as Žilina, Nitra or Košice.
- Hypothesis No. 3: **Geometry as a tool for compensating decor and a bearer of quality.** The basic arrangement of the main (dominant) facades, such as the rhythm of windows or the division of surfaces, is directly determined in the period observed by precise geometric

rules, which are the main bearer of the quality of the work. This geometry purposefully replaces the missing complex spatial solutions (such as *Raumplan* or *Plan Libre*), thus giving the building a modern face while maintaining the traditional (hybrid) method of construction.

As a response to the current state of research, we present our own research methodology subsections 3.1 and 3.2 below. Its primary goal is to replace the subjective assessment of proportions with objective measurements and mathematical proofs. We proceed from the assumption that the classical proportional canons and principles of Euclidean geometry represent timeless, although often neglected in contemporary architectural practice, tools of creation. In doing so, we consider it necessary to return these principles to the centre of attention and show their lasting validity, because through clear calculations and drawings, we can precisely substantiate and bring the hidden qualities of works closer not only to the professional public, but also to the general public.

3.1 Identification, archival research and digitization

1. Categorization and selection of a representative sample - the process begins with defining a set of structures (detached family houses and villas). The selection is conditioned by an effort to capture stylistic and authorial diversity and should include works by key figures of the architectural scene of the time. The criteria are architectural quality and the availability of primary sources.
2. Primary data collection: drawing on documentation of historical drawings from archival funds and period professional literature. Through digital analysis, the inclusion of any lost works permits us

to re-examine and precisely interpret the proportional qualities of objects that no longer physically exist. In this way, the research contributes to a deeper theoretical understanding of any lost architectural substance and its original compositional principles.

3. Digitization and vectorization in a BIM environment - redrawing of archival documents (facades and floor plans) into the Archicad environment. Due to the absence of dimensioning, the scale of the models was determined by calibration according to the graphic scale on the originals and verification through the standard dimensions of building elements. This uniform processing eliminates the distortion of historical paper documents and creates an accurate basis for subsequent geometric measurements.

3.2 Geometric analysis

Geometric analysis is inspired by classical architectural procedures for finding ideal proportions (regulation lines, the canon of the golden section, Euclidean and root modules), which are applied using modern tools. The process seamlessly connects historical archival research and data digitization with a quantitative evaluation. This evaluation ranges from an analysis of the overall proportional framework and compositional dominants, through the visual identification of geometric nodes in the raster, to the automated statistical verification of the rhythm of the facades using a custom-programmed algorithm. However, this algorithm is not intended to serve as the primary computational program, nor is it the desired “product” of our research. It is merely a practical tool that simplifies manual work consisting of numerous partial calculations and their classification.

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3.2.1 Determining the primary proportional framework of the dominant facade

The aim of this step is to identify the basic geometric system into which the overall composition of the front facade is inscribed. Focusing the analysis exclusively on the main facades of the buildings ensures the methodological purity and long-term sustainability of the research, while allowing for a high quality of the data to be achieved when processing the entire set of villas. The parameters monitored are:

1. *a* (width): the total horizontal dimension of the facade measured between the outer edges of the object (given in mm),
2. *b* (height): the total vertical dimension of the facade measured from the line of the landscaped terrain to the highest point of the main attic or cornice (given in mm).

The aspect ratio (*a* : *b*) calculated is then compared with the theoretical compositional systems. A tolerance of 3% is applied during the

evaluation, which eliminates minor inaccuracies arising during the period of construction or during the digitization of any archival materials. The resulting categorization of the object can then fall into two categories:

1. irrational systems - conformity with the golden ratio ($\phi \approx 1.618$) or root systems ($\sqrt{2} \approx 1.414$; $\sqrt{3} \approx 1.732$, ...)
2. rational (modular) systems - the presence of integer ratios based on Euclidean geometry (square 1:1, ratio 3:2, 4:3, etc.)

3.2.2 Analysis of proportions and relationships of compositional dominants

This step focuses on the internal division of the facade. We examine how the compositional dominant of the facade (e.g., a projecting tower, a risalit, or a main entrance block) and the partial dimensions of the facade relate to the overall dimensions of the building. The goal is to determine whether the architect used the same rules for the whole as for these prominent elements. The parameters monitored are:

1. a_D, b_D (dominant dimensions - separately measured width and height of key volumes of the facade (given in mm),
2. mutual correlation: comparing the dimensions of the dominant versus the whole ($a : a_D, b : b_D, a : b_D, b : a_D$ and inverse ratios), the dominant's own ratio ($a_D : b_D$ and inverse ratio) and correlation to the internal division ($a_n : a_D, b_n : b_D$ for all the partial lengths and their inverse ratios).

The objectives of the analysis of the internal structure are:

- searching for hidden geometric relationships, i.e., verifying whether important dimensions are not identical (for example, whether the height of the compositional dominant is not equal to the total width of the house),
- verifying modularity: searching for

connections and relationships between individual parts, using rational systems (modules) or irrational systems,

- identifying the canon of the dominant: observing whether the accented mass is designed in a stricter geometry (e.g., a pure golden ratio) than the rest of the facade.

3.2.3 Identifying compositional nodes and placing key details

In this step, we apply a combined geometric analysis to the main facade of the building. We use a rational modular grid M , the parameters of which were exactly calculated in the first step of the analysis, in combination with an irrational golden section template (ϕ). The goal is to define the overall static outline through the centre of the composition (S) and the main axes (oa, ob) and to identify the compositional nodes (U_n) on the axes of the golden section in order to verify whether the positions of the most significant architectural accents are subject to exact geometric regulation. At the same time, we will directly read from the graphic drawing and visually evaluate to what extent the areal division of the rest of the facade obeys the rational modular grid drawn. The parameters monitored are:

1. S (centre of the composition): the intersection of the main diagonals that define the basic rectangle of the $a \times b$ façade (its geometric centre),
2. o_a, o_b (principal axes): vertical and horizontal central axes that pass through the geometric centre (S) and define the basic symmetry of the composition,
3. U_n (geometric nodes): intersections of the key lines on the axes of the golden ratio template (ϕ), on which we assume the intentional placement of key architectural details,
4. M (modular grid): regulatory lines L (vertical and horizontal) of the modular

grid calculated and their alignment with the regular openings and solid surfaces of the facade,

5. accented elements: the location of the main entrance, distinctive cornices, balcony edges, specific artistic details or dominant windows on the facade.

The objectives of the node and grid analysis are:

- an analysis of the overall compositional arrangement, i.e., an evaluation of the facade as a whole in relation to its static geometric centre (S) and the main central axes (o_a, o_b). The aim is to examine whether the architect identified the visual focus of the facade with its geometric centre (thereby achieving static symmetry), or whether the distribution of the masses and the centre of gravity were deliberately shifted away from these main axes, thereby creating an asymmetrical modern tension in the composition,
- verification of a geometric intervention, i.e., determining whether the key elements and accents of the facade correlate with the nodes (U_n) and axes of the golden ratio within the specified permissible deviation (Δ up to 3%),
- connection with the modular grid, i.e., a visual verification based on a graphic drawing of to what extent the surface organization of the facade fits into a rational grid. Whether the window axes, floor heights, wall edges or the division of tracts respect the regulatory lines (L) of the modular network determined are assessed.

3.2.4 Analysis of the rhythmic structure and linear division using a computational algorithm

This step focuses on a detailed division of the facade area using horizontal (h_n) and vertical (v_n) lines (axes). The goal is to identify the rhythm of the facade and determine whether the placement of window openings and cornices follows an exact geometric canon. The analysis is based on a custom computer script written in the Python programming language, which reads the input data of the facade in the form of intervals from a CSV file and converts it into a point system, that can be analyzed.

The parameters monitored are:

1. h_n (horizontal axes): elevation levels of the terrain, windowsills, window lintels, balconies and attics,
2. v_n (vertical axes): axes of the window and door openings, widths of the inter-window pillars.

The goals of the rhythm and articulation analysis are:

- identification of the golden ratio: the algorithm systematically goes through all possible combinations of the triples of points ($v_1, v_2, v_3 \dots$) that define the facade. It calculates the lengths of the segments between them, determines their mutual ratio, and then verifies whether this ratio corresponds to the golden ratio, while accepting a limit deviation Δ of up to 3%,
- identification of root systems: in order to check the presence of networks other than modular ones based on the golden ratio, the algorithm tests the calculated segment ratios against a predefined root matrix in parallel. Here too, the presence of a geometric rule is confirmed only if it matches the maximum permissible deviation Δ of up to 3%,

- quantitative verification of compositional nodes: instead of visually estimating the modular network, the program mathematically verifies every single existing proportional link between the elements. Both successful matches (marked 1) and failures (marked 0) for the golden ratio and square root proportions are automatically written to the output CSV file, which allows for a statistical evaluation of the canon applied.

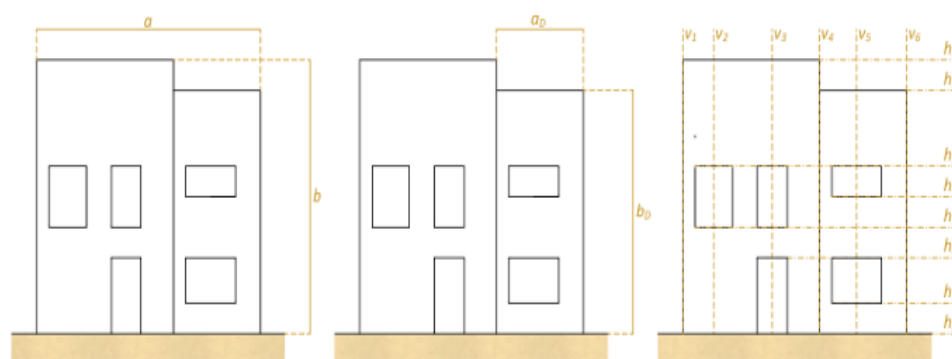


Fig. 1 Graphic definition of the dimensions a , b , a_D , b_D , h_n , v_n for determining the outline frame

3.2.5 Correlation of the external geometric canon and internal spatial structure

This step represents a synthesis of the previous findings (sections 3.2.1 - 3.2.4) and their confrontation with the internal layout and structural system of the object. The aim is to identify the degree of compliance or non-compliance between the geometric envelope and the actual structural system. The parameter monitored is:

- V_{rin} (vertical regulatory lines): axes drawn from the edges of the offset parts of the facade to the floor plan, based on which we can analyse the visual and functional relationship between the external surface envelope and the internal spatial arrangement.

The objectives of the analysis of the internal spatial structure are:

- structural projection: the degree of the direct correspondence between the vertical regulatory lines of the facade and the position of the internal load-bearing walls or columns in the floor plan,
- confrontation of the dominant feature in the floor plan: an analysis of whether the dominant feature of the facade logically and truthfully reflects an important point of the interior, or whether the facade only serves to create an autonomous modern expression that does not depend on the interior layout,
- operational logic of the floor plan: evaluation of the operational logic of the floor plan and its response to the external composition.

4 CASE STUDY: THE JAROŇ VILLA IN BRATISLAVA, SLOVAKIA

The Ing. Jaroň villa at Uhrová Street 4 in Bratislava (1929) represents one of the most frequently representative works concerning domestic functionalism and the most frequently published work concerning Slovak villa architecture abroad. It represents the mature work of the authorial duo Alois Balán (1891–1960) and Jiří Grossmann (1892–1957). The building reflects their departure from early Decorativism towards an architecture of pure forms (Fig. 2a).

The villa gradually underwent many reconstructions and extensions, which negated its significant proportions, thereby turning it into a boring conventional building. Finally, it was demolished in 2011. The volumetric

composition, which rationally fitted into the plot, worked with basic cubic shapes. The focus of the entire design was the street facade on which the architects applied considerations of proportion, the fullness of surfaces, and the distributions of openings. A distinctive composition of mutually displaced volumes with the unmistakable shape of a steep hipped roof dominated (Berka & Bahna, 2016).

A clear and rational approach to shaping the facade of the house created an ideal prerequisite for an exact geometric analysis and the search for hidden proportional canons or an internal modular series. For this reason, as well as because of the exceptional position of the Jaroň villa in the history of Slovak architecture, we will demonstrate the practical application of the proposed methodology using it as our example.

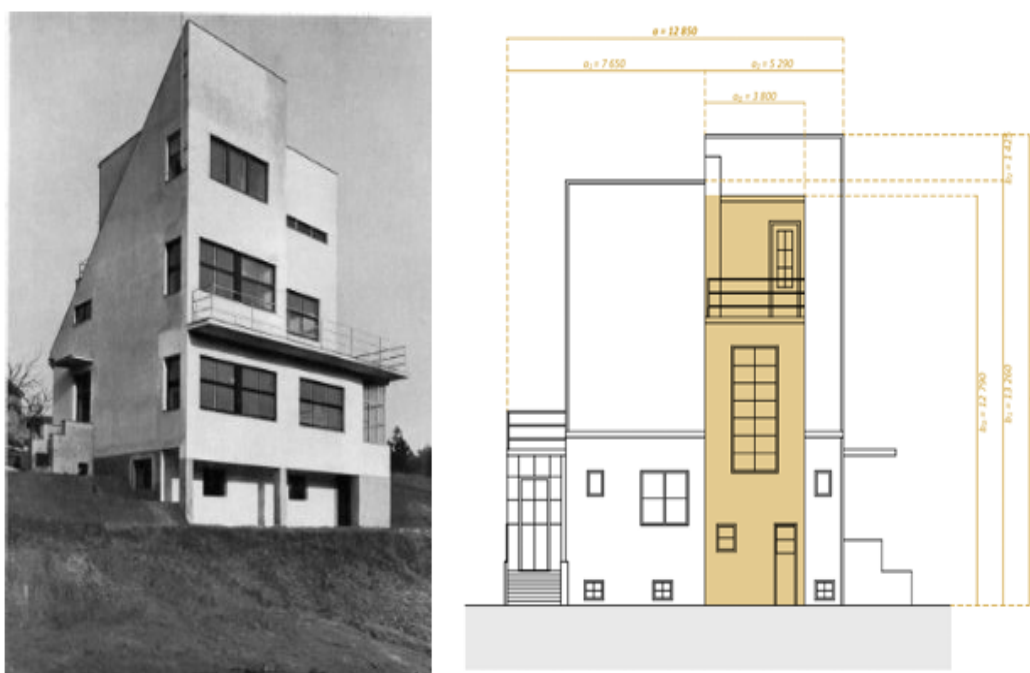


Fig. 2 a, b: Ing. Jaroň villa in Bratislava (Berka & Bahna, 2016) and graphic diagram of the basic input data

The following part of this paper presents an example of the use of our proposed research methodology using the Jaroň villa as an example. The numbering of individual subsections is in accordance with the points

of the methodology specified in Section 3.2. The geometric analysis was preceded by the acquisition and preparation of the input data (Fig. 2a,b) in accordance with Section 3.1. of the proposed methodology.

4.1 Determining the primary proportional framework of the dominant facade

a) Monitored parameters (according to Fig. 2a):

$$a = 12,850 \text{ mm}$$

$$b = 14,685 \text{ mm}$$

b) Comparison method and canon identification:
ratio $a : b = 0.875$

c) Resulting categorization of the object:

Rational (modular) system:

$$a : b = 7 : 8 = 0.875; \Delta = 0.000 \%$$

Based on our calculations, we determined that the resulting primary framework of the main (dominant) facade was built on a rational grid and was based on the ratio $a : b$. The facade of the building was inscribed in a vertically oriented rectangle in the ratio $7 : 8$ with a deviation of 0.000% , which is generated by repeating the basic module $M \approx 1,836 \text{ mm}$, which was determined with a deviation of 0.018% .

Module size calculations:

$$M_a = a / 7 = 12,850 \text{ mm} / 7 = 1,835.714 \text{ mm}$$

$$M_b = b / 4 = 14,685 \text{ mm} / 4 = 1,835.625 \text{ mm}$$

$$M = (M_a + M_b) / 2$$

$$= (1,835.714 + 1,835.625) / 2$$

$$= 1,835.670 \approx 1,836 \text{ mm}$$

$$\Delta = |(1,836 - 1,835.670) / 1,836| \times 100$$

$$= 0.018 \%$$

4.2 Analysis of the proportions and relationships of the compositional dominants

a) The main compositional dominant of the facade is the asymmetrically placed stair tower a_D , b_D (the shaded part in Fig. 2b). The analysis of the parameters monitored refers to the monitored parameters a and b and the module $M = 1,836 \text{ mm}$ calculated. Monitored parameters:

$$a_D = 3,800 \text{ mm}$$

$$b_D = 12,790 \text{ mm}$$

b) Cross-correlation:

The matrix of the basic ratios between the total (a , b) and dominant (a_D , b_D), the intrinsic dominant ratio, and the correlation to the internal division (a_n , b_n), are shown in Tabs. 1 and 2.

c) Finding the hidden geometric relationships:

$$a \approx b_D$$

The width a is approximately equal to the height of the dominant b_D with a deviation of 0.460% .

$$b_1 \approx b_D$$

The partial height b_1 is approximately equal to the height of the dominant b_D with a deviation above the tolerance limit of 3.700% .

Tab. 1 Input values for calculating the correlation coefficient [mm]

a	b	a_D	b_D	a_1	a_2	b_1	b_2
12,850	14,685	3,800	12,790	7,650	5,290	13,260	1,425

Tab. 2 Matrix of proportional relationships

Relationship category	Monitored ratio	Calculation [-]	Inverse ratio	Calculation [-]	cat.	Δ [%]
Basic ratio	$a : b$	0.875	$b : a$	1.143	$7 : 8$	0.000
Dominant versus whole	$a : a_D$	3.382	$a_D : a$	0.296	$10 : 3$	1.460
	$b : b_D$	1.148	$b_D : b$	0.871	$8 : 7$	0.450

Relationship category	Monitored ratio	Calculation [-]	Inverse ratio	Calculation [-]	cat.	Δ [%]
	$a : b_D$	1.005	$b_D : a$	0.995	1 : 1	0.460
	$b : a_D$	3.864	$a_D : b$	0.259	27 : 7	0.178
Own dominant ratio	$a_D : b_D$	0.297	$b_D : a_D$	3.366	3 : 10	1.000
Correlation to internal division	$a_1 : a_D$	2.013	$a_D : a_1$	0.497	2 : 1	0.650
	$a_2 : a_D$	1.392	$a_D : a_2$	0.718	$\sqrt{2}$	1.570
	$b_1 : b_D$	1.037	$b_D : b_1$	0.965	1 : 1	3.700
	$b_2 : b_D$	0.111	$b_D : b_2$	8.975	1 : 9	0.099

d) Verification of the modularity:

In the relations to the total width to the width of the dominant ($a : a_D$), the total width of the object is related to the width of the dominant by the rational canon 10 : 3 with a deviation of 1.460 %. In the relationship of the total height to the height of the dominant ($b : b_D$), the total height of the object is related to the height of the dominant by the rational canon 8 : 7 with a deviation of 0.450 %. In the cross-relations of the total height to the width of the dominant ($b : a_D$) follows the ratio rational canon 27 : 7 with a deviation of 0.178 %. At the level of the internal division of the partial width to the width of the dominant ($a_1 : a_D$) the ratio rational canon 2 : 1 follows with a deviation of 0.650 %, in the case of $a_2 : a_D$ the ratio irrational canon $\sqrt{2}$ follows with a deviation of 1.570 %, and the division of the partial height to the height of the dominant ($b_2 : b_D$) the rational canon ratio of 1 : 9 follows with a deviation of 0.099 %.

e) Identification of the dominant canon:

Based on the calculation, it is clear that the overall facade and the dominant are designed in a rational (modular) system. The design of the whole in relation to the dominant represents the use of a stricter geometry based on a smaller deviation. The

overall facade ($a : b$) is defined by a rational ratio of 7 : 8 with a deviation of 0.000 %, while the own ratio of the dominant ($a_D : b_D$) is defined by a rational ratio of 3 : 10 with a deviation of 1.000 %.

4.3 Identifying compositional nodes and placing key details

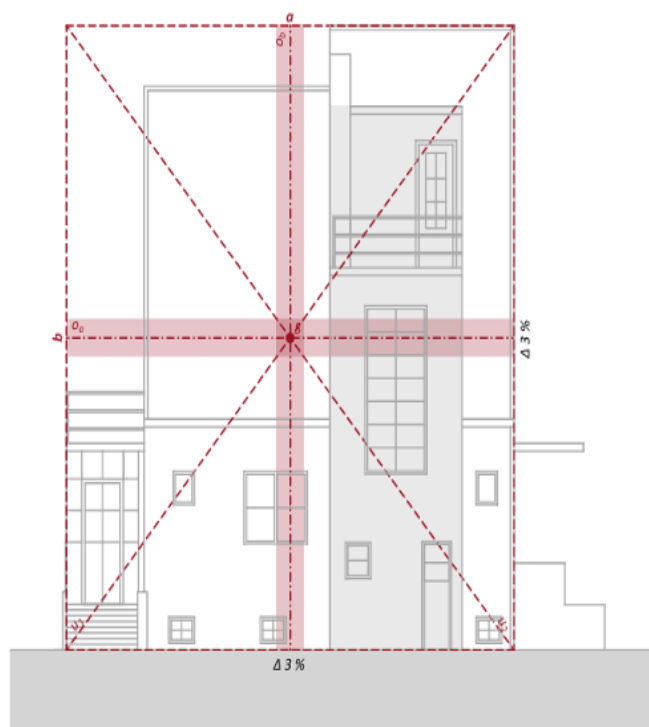


Fig. 3 Geometric template of the centre of the composition S in the context of the dominant

- a) Monitored parameters (according to Fig. 3):
 S - centre of the composition (determined geometrically)
 U_1, U_2, U_3 - geometric nodes (determined geometrically)
 o_a, o_b - horizontal and vertical centreline (determined geometrically)
 $M = 1,836 \text{ mm}$

- b) Analysis of the overall compositional arrangement:

The geometric centre of the composition (S), which is defined by the intersection of the main diagonals (u_1, u_2), does not define any significant division or element on the facade. The main horizontal axis (o_a) does not define any significant division or element on the facade. The main vertical axis (o_b) does not define any significant division or element on the facade. The object can be classified as asymmetrical with a strong modern compositional tension in the distribution of the masses.

- c) Verification of the geometric interference:

The regulatory template of the golden section (ϕ) was applied to the composition of the facade, which was derived from the basic proportional dimensions of the object a, b (Fig. 4). The graphic diagram depicts those cases in which the regulatory lines exactly correlate with the architectural elements. Three (3) compositional nodes were created on the facade analysed. The compositional node U_1 correlates with the left edge of the highest mass within the specified tolerance range ($\Delta \leq 3\%$). The compositional node U_2 correlates with the edge of the end of the dominant (terrace) within the specified tolerance range ($\Delta \leq 3\%$). The compositional node U_3 correlates with the edge of the end of the protrusion of the entrance to the object within the specified tolerance range ($\Delta \leq 3\%$). The position of the golden section in the horizontal direction on the facade clearly delineates the edges of the terraces and, in the vertical direction, clearly delineates the offset of the object's mass.

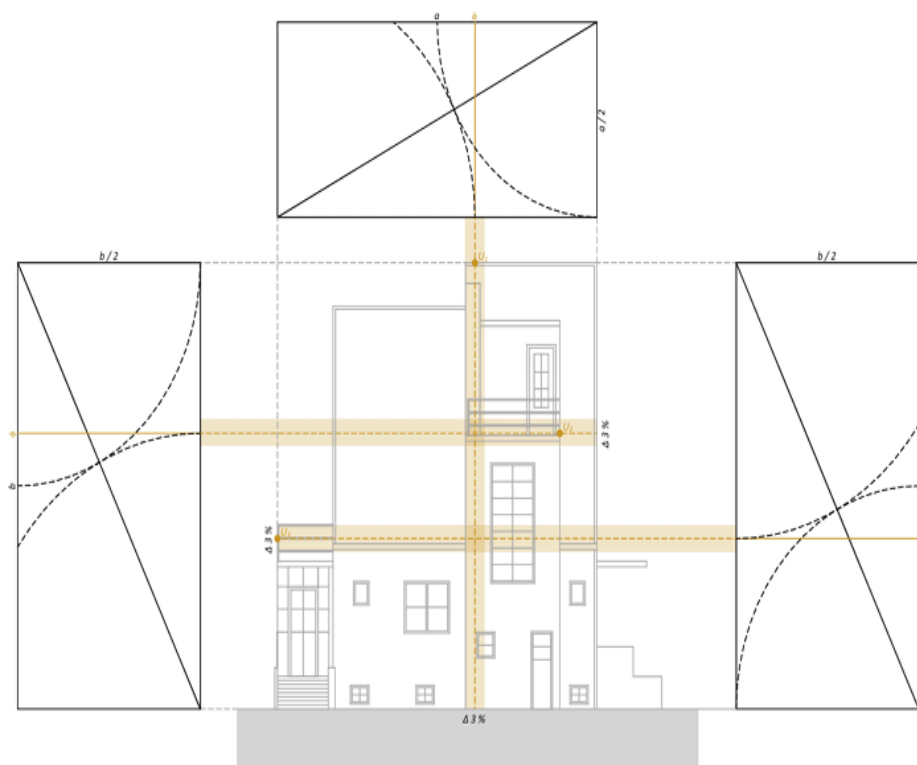


Fig. 4 Geometric template of the golden rectangle defining compositional nodes u_n

d) Connection with the modular grid:

The visual verification based on the graphic drawing (Fig. 5) confirms the high degree of the integration of the areal organization of the facade into a rational grid. The modular network applied with a basic module $M = 1,836$ mm, which defines the overall areal proportion in the ratio $a : b = 7 : 8$, serves as the compositional framework of the entire facade. The regulatory lines established exactly correlate with the architectural elements. The vertical lines L_{v2}, L_{v5}, L_{v7} define the basic division of the object within the established tolerance band ($\Delta \leq 3\%$). The horizontal lines L_{h2}, L_{h4}, L_{h6} define the basic division of the object within the established tolerance band ($\Delta \leq 3\%$). The geometric centre of the composition S lies between the vertical axes L_{v4} and L_{v5} and on the central horizontal axis L_{h5} .

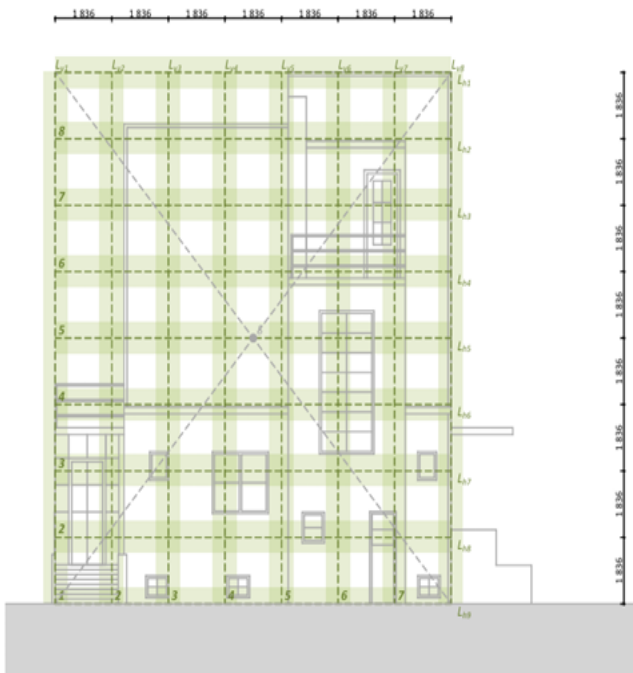


Fig. 5 Geometric template of modular network, $M = 1,836$, $a : b = 7 : 8$

4.4 Analysis of the rhythmic structure and linear division using a computational algorithm

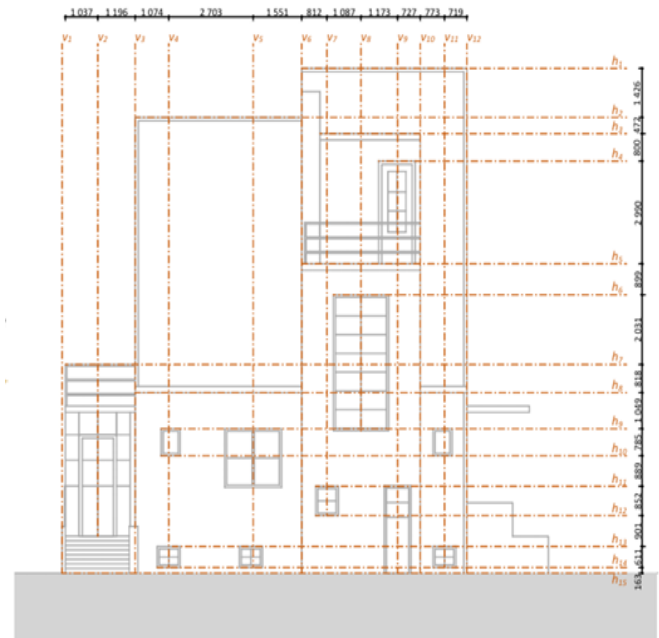


Fig. 6 Geometric template of the horizontal (h_n) and vertical (v_n) axes

a) Identification of the golden ratio (according to Fig. 6):

The algorithm checked all the possible triples of the points ($v_1 - v_{12}, h_1 - h_{15}$) and their segment ratios with a tolerance of Δ up to 3 %. In the vertical direction, out of a total of 220 combinations tested, the program confirmed the golden ratio in only 8 cases, which represents a negligible proportion of 3.636 %. In the horizontal direction, out of a total of 455 combinations tested, the program confirmed the golden ratio in only 9 cases, which represents a negligible proportion of 1.978 %. Based on these values, we can assume that this is not a conscious composition based on the golden ratio.

b) Identification of the root systems (according to Fig. 6):

The algorithm checked all the possible triples of the points ($v_1 - v_{12}, h_1 - h_{15}$) and their segment ratios with a tolerance of Δ up to

to 3 %. In the vertical direction, out of a total of 220 combinations tested, the program confirmed the golden ratio in only 8 cases, which represents a negligible proportion of 3.636 %. In the horizontal direction, out of a total of 455 combinations tested, the program confirmed the golden ratio in only 9 cases, which represents a negligible proportion of 1.978 %. Based on these values, we can assume that this is not a conscious composition based on the golden ratio.

- b) Identification of the root systems (according to Fig. 6):

The algorithm checked all the possible triples of the points ($v_1 - v_{12}$, $h_1 - h_{15}$) and their segment ratios with a tolerance of Δ up to 3 %. In the vertical direction, out of a total of 220 combinations tested, the program confirmed the square root in 66 cases, which represents 30.000 %. In the horizontal direction, out of a total of 455 combinations tested, the program confirmed the square root in 104 cases, which represents 22.857 %. Based on these values, we can assume that this may be a conscious composition based on square roots.

4.5 Correlation of the external geometric canon and internal spatial structure

- a) Parameters monitored (according to Fig. 7):

V_{r11} , V_{r12} , V_{r13} , V_{r14} , V_{r15} , V_{r16} - vertical control lines

- b) Structural projection:

The vertical regulation lines (drawn from the edges of the offset parts of the facade) are aligned with the supporting system of the building. The vertical lines V_{r13} and V_{r14} confirm that the edges of the dominant feature in the floor plan copy the supporting wall that separates the staircase section from the main living spaces. The vertical line V_{r12} confirms that the edge of the entrance in the floor plan copies the supporting wall that separates the living space from the annex. The facade directly recognizes the

basic structural division of the building into individual sections.

- c) Confrontation of the dominant features in the floor plan:

The dominant feature of the facade selected truly reflects the key interior space. It is a direct visual projection of the vertical communication core to the exterior. The external aesthetics of the facade are in harmony with the internal spatial arrangement.

- d) Operational logic of the floor plan:

The analysis of the traffic lines confirms that the dominant feature of the facade forms the main distribution node of the movement in the house. After passing through the entrance, the traffic is connected to this communication core, from which the internal movement to all the residential and utility rooms on both floors subsequently unfolds. The architectural composition of the facade thus directly visualizes the internal operational hierarchy from the outside.

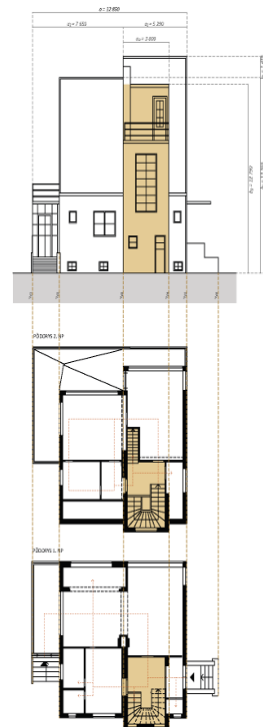


Fig. 7 Dominant facade and relationship to the floor plan analysed, scheme for determining the primary proportional framework a , b and relationships of compositional dominants a_d , b_d

4.6 Partial conclusion

The summary table is not just a formal summary of the partial data, but a key tool for objectifying the architectural research. While traditional architectural theory often evaluates the composition of facades based on subjective visual interpretations, the proposed synthetic model transforms an in-depth geometric analysis into exact, quantifiable parameters.

Tab. 3 presents a sample of the output using a model situation based on the example of the Jaroň villa, which can, for example, serve as an analytical catalogue sheet for the house. This approach precisely demonstrates the application of modular systems and the structural truth of the solitaire form, but above all, it creates a transparent basis for a systematic comparative analysis of interwar modernism.

Tab. 3 Comprehensive evaluation of the geometric and proportional analysis of the street facade of the

Analytical category	Value/finding
1. Determining the primary proportional framework of the dominant facade	
Primary proportional framework of the facade	rational system, 7 : 8
Basic module (M)	$M = 1,836 \text{ mm}$
Deviation M (Δ)	$\Delta = 0.018 \%$
2. Analysis of proportions and relationships of compositional dominants	
Proportional framework of the dominant	rational system, 3 : 10
Mutual correlation of the whole and the dominant	yes
Stricter geometry applied to	the mass of the whole
3. Identifying compositional nodes and placing key details	
Overall compositional arrangement	asymmetrical
Delineates the centre of the composition (S) significant division/element?	no
Do golden ratio diagrams outline a significant division/element?	yes (3 composition nodes)
Matching the modular grid to the main mass of the house	yes
Matching the modular grid with the hole spacing	rather not
4. Analysis of rhythmic structure and linear division (tolerance $\Delta \leq 3 \%$)	
Identifying the golden ratio - vertical	3.636 %
Identifying the golden ratio - horizontal	1.978 %
Identification of the root system - vertical	30.000 %
Identification of the root system - horizontal	22.857 %
5. Correlation of external geometric canon and internal spatial structure	
Compliance of facade control lines with the load-bearing system	yes
Projection of the internal communication core onto the facade	yes

5 DISCUSSION

Our article focuses on the issue of the compositional and proportional analysis of architectural works of interwar architecture. This work focuses on raising awareness of the quality of interwar architecture, which, from an architectural perspective, is not as easily defined as older architecture designed in specific styles. Given the current state of heritage research in Slovakia, this work is therefore intended primarily for specialists in the field. Thanks to the proposed methodology, it is possible to develop a database of architectural works with precise parameters, which can subsequently serve as one of the tools for presenting Slovakia's architectural heritage to the public.

Based on the verification of the proposed methodology using the model example of the Bratislava villa Jaroň and the findings achieved, several relevant lines for follow-up research can be seen, which could help to deepen knowledge of this area. At the same time, we can assess the validity or invalidity of the hypotheses formulated. Research hypothesis No. 1 was confirmed. The case study demonstrated that the villa investigated exhibits an exact geometric order built on a rational modular system with a deviation well below the established tolerance limit.

The current research was primarily focused on an analysis of the two-dimensional projection of the dominant facade. Follow-up research could focus on the complex spatial composition of the entire structure. This approach would require a change in methodology from planar (2D) to volumetric (3D), which would provide a more comprehensive understanding of the building's geometry, without being limited solely to its front facade. However, we can assume that the findings would not change significantly, since most architectural works of that period were designed with an emphasis on the quality of the front facade. The other facades were

supplementary and primarily served the needs dictated by the building's layout.

Given the time and analytical complexity of such a procedure, it would be appropriate to apply it in the form of an in-depth case study of one selected object, which would thereby achieve the most detailed understanding of the mass concept. The research was based on available archival project documentation, which in certain cases may not absolutely correspond to the actual implementation of a building. The next step to take to increase the accuracy of a compositional and geometric analysis would be the exact orientation of the selected objects directly on site using modern technologies, e.g., laser scanning or advanced photogrammetry. Such data would allow verifying geometric interventions with micrometric accuracy and revealing any implementation deviations from the original creator's intention.

To verify the broader validity of the compositional principles identified and their definition as a broader period phenomenon, as well as to verify the correctness of the proposed methodology on a broader scale, it is appropriate to expand the database of the objects analysed. A larger database would permit the application of more advanced statistical methods that could demonstrate the representation of the exact percentage of the application of proportional rules (e.g., the golden ratio) across different typological types of buildings in the period under study. Instead of a cross-sectional examination of various objects by several authors, which is one of the options, further research could also choose a monographic approach.

A detailed comparative analysis of the portfolio of one specific architect would allow for the exact mapping of the chronological development of his personal style. Tracking the transformation of a particular author's compositional approaches over time (e.g., the gradual transition from the strict central

symmetry of early works to the functionally conditioned asymmetry of later work) would yield valuable insights into the internal intellectual development of key figures in our architecture of the first half of the 20th century. At the current stage of research, it is not possible to reliably prove the truth or falsity of the related hypothesis No. 2, as it would be necessary to analyse a larger set of villas. Ideally, it should be a sample of objects exhibiting stylistic diversity, which would permit examining the universality of geometric rules across different approaches.

The research sample of buildings, from which we finally chose the Jaroň villa for practical verification of the methodology, was in the Bratislava area. For a comprehensive assessment of the development of domestic architecture in the period in question, it is necessary to analyse villa architecture in other regions of Slovakia. An even greater benefit would be provided by a comparative analysis with surrounding European centres of modern architecture (e.g., Brno, Prague or Vienna), which would precisely confirm whether Bratislava's architectural production followed the same proportional and compositional laws as the international avant-garde, or whether it retained regional deviations. Future research could use the data obtained on proportions and the golden ratio as input parameters for algorithmic design and machine learning. Creating a database of compositional rules from historical villas could be used to train neural networks that could be able to re-generate or automatically evaluate proportional schemes not only in historical buildings, but also in contemporary architectural designs.

For the purposes of our work, however, the primary focus was not on highlighting the use of contemporary computational methods, such as machine learning, but rather to highlight the high quality of interwar architecture, with the form of exact calculation serving merely as a means and representing more of a hint and demonstration of the direction research might

take in its future wider application. It is likely that this approach could be more time-efficient; on the other hand, it is somewhat at odds with the principles of Euclidean geometry itself, since the observer of a building, or the user of such a program may not immediately perceive the individual procedural steps that are important for understanding the qualitative values of interwar architecture, and the “finished” result may not be fully comprehensible at first glance.

Through geometric analysis, we confirmed the validity of hypothesis No. 3 within the scope of the case study. The analysis demonstrated that the geometry of the facade served as a compensatory tool for the “missing” ornament. Since architects often had to work with a traditional structural system of load-bearing walls in their homes, which did not allow for the radical application of *Plan Libre* or *Raumplan*, they purposefully shifted the modern expression of the building to a plane of the strict planar geometry of the main facades. The assumption that everything (including the precise rhythm of the windows) is subordinated to abstract geometric rules was, however, refuted. The computational algorithm showed that the presence of the golden ratio is minimized in the detailed arrangement of the facade. When placing window and door openings precisely, the calculations revealed the presence of square root systems, with the position of the openings in the grid primarily adapting to more pragmatic factors, such as the requirements of the internal operation and the design limits of the building materials available at the time. They represent a necessary and rational compromise between the pursuit of geometric perfection and the practical structural and material limits of the time.

6 CONCLUSIONS

The relationship between beauty and mathematics is a key question that has shaped architecture since time immemorial.

Nevertheless, previous professional reflections on domestic interwar architecture in assessing its aesthetic and harmonious qualities has long relied mainly on visual judgment and theoretical assumptions about the ubiquity of the golden ratio. Due to the absence of an exact, quantifiable approach that would underpin architectural quality with verifiable data, the true compositional logic of many significant objects of interwar architecture remained largely misunderstood. The present article fills this gap and, through its own analytical methodology, replaces subjective assessment of proportions with objective measurement and mathematical evidence.

By the algorithmic verification of the dominant facade, we found that the Jaroň villa in question was not designed based on intuition. On the contrary, its architectural expression was anchored in rational, modular proportional systems and was subject to a well-thought-out compositional canon. While the gross volumes of the buildings are exactly defined by Euclidean geometry and simple fractional ratios, the detailed rhythm is determined by intersections based on root systems. The golden ratio plays a role exclusively in delineating the compositional nodes of gravity. This mathematical precision was not just a formal gesture for its own sake on the part of the creators, but a pragmatic response to the structural limits of the period materials and a tool with which the architects visually compensated for the missing spatial complexity of the internal layout.

Based on the results of our geometric analysis, our research reaches its most fundamental finding, i.e., the architectural beauty and harmony of interwar villas are not just an abstract or individual feeling of the observer, but represent an exactly calculable, verifiable, and quantifiable category. The interwar period is today evaluated by society as a whole and professionally as an exceptionally positive and valuable stage of our architecture. We therefore proceed from the assumption that

the classical proportional canons and principles of Euclidean geometry represent timeless tools of creation. The results of this research not only provide a sustainable tool for the protection and restoration of our cultural heritage but also show a possible future direction. We consider it necessary to return these principles to the centre of scientific attention, as well as to contemporary architectural teaching and practice. Although strict geometry is not the only criterion of quality, its conscious application is a proven tool that is desirable to reach for whenever we need to impart lasting value to an architectural work.

DATA/CODE AVAILABILITY

The research data and source code for the proposed script are available from the first author upon reasonable request.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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