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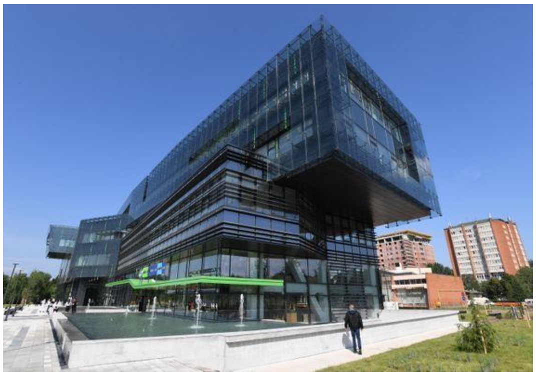

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PREFACE

The primary goal of the SINARG 2023 conference is to present contemporary achievements in the scientific and practical aspects of architecture and civil engineering. The organizers of the conference aimed to facilitate the participation of both national and international professionals in theoretical and experimental research related to the processes of design, project management, construction, and building maintenance within the construction industry.

Simultaneously, this scientific conference serves as a platform for exchanging experiences and information regarding innovations and advancements in planning, design, new materials, and construction and reconstruction technologies within the fields of architecture and civil engineering.

Therefore, this conference should serve as a forum where experts from civil engineering, architecture, and other related fields have the opportunity to present the results of their research. In that context, conference topics have been carefully selected to provide focus on current issues in the field and encourage productive discussion bringing fresh and original insights and concepts to the forefront.

More than 180 paper proposals have been submitted to the conference. A single-blind review process was used to assess the full papers. The reviewers are esteemed scientists holding PhD degrees in the same field as the paper's topic. There are more than 70 reviewers from ten countries who have significantly contributed to the scientific quality of the conference, and their names are printed in the proceedings.

A total of 142 full papers have been accepted for publication. Some of the papers have been selected for publication in our journals, with nineteen papers in Facta Universitatis: Architecture and Civil Engineering and nine in the Journal of the Faculty of Civil Engineering and Architecture. The conference proceedings consist of 114 papers divided into two volumes.

The total number of authors and co-authors accepted for publishing at SINARG 2023 exceeds 320. Out of this number, more than 80 authors come from abroad, representing 19 countries (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Germany, Greece, Hungary, India, Indonesia, Netherlands, North Macedonia, Montenegro, Oman, Poland, Romania, Serbia, Slovakia, Turkey, United Kingdom).

The editors express their gratitude to all the authors for their participation and to the reviewers for their valuable comments, which have contributed to the improvement of the original manuscripts and have enhanced the overall quality of the conference..

Niš, September 2023 — *Editors*

CONTENTS

TOWARDS NUMERICAL ARCHITECTURAL ORDER IDENTIFICATION: EXPRESSING CAPITAL MORPHOLOGY BY USING DYNAMICS OF ITS PARAMETERS

Djordje Mitrović[1], Djordje Djordjević[2], Mirjana Devetaković[3], Gordana Djukanović[4]

Abstract

Previous subject-related research, that describes stylistic peculiarities of artefacts by taking into account their morphometric/geometric characteristics, explicates the results (used to differentiate them in terms of style they belong to) mainly descriptively – by evaluating the obtained data visually.

The narrower aim of this Paper is to explicate the mentioned characteristics numerically/quantitatively by transposing stylistic-wise parameters (descriptors of fractal and non-fractal nature), previously investigated by the actual authors, into the form of dynamics of their values namely explicators. Therefore, the main research questions of this study are both how to express artefact morphology by using dynamics of its parameters and, thus, how to numerically/quantitatively identify architectural style concrete artefact belongs to.

To achieve that scientifically, a triplet of capital samples (as the most distinctive elements among artefacts), namely their digital 3D models, are employed per each fundamental classical architectural order (Doric, Ionic, and Corinthian). The subject of this Paper is to establish relevant morphometric/geometric indicators not only in the form of explicators mentioned above, but qualifiers too, enabling so: to numerically express capital morphology, namely to quantitatively estimate levels of intra-similarity of capitals assumed to belong to the same order, and inter-dissimilarity of those assumed to belong to different ones. Both types of the established indicators refer to capital contours which are positioned in mutually equidistant transverse section planes (defined per each chosen capital sample of each of the analysed orders).

The wider research aim refers to both: (a) a possibility to numerically/quantitatively identify order a concrete fragment of capital/artefact belongs to in terms of recognising it computationally (as confidently as possible from the mathematical probability point of view), and (b) to perform morphology-wise capital/artefact segmentation.

Presented innovative methodology brings up a more reliable possibility to identify architectural order "stylistically unknown capital" belongs to – by using a newly introduced indicator (in the form of dynamics) to express its morphology numerically/quantitatively. Future research will be dealt with software-wise automation of stylistic decoding steps (rough capital classification and order-belonging estimation).

Key words: *dynamics, fractal object, numerical stylistic analysis, morphology-wise parameters, classical architectural order capital*

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1. INTRODUCTION

To express artefact morphology in the scientifically sustainable way, various parameters of different nature have to be employed. More suitable ones are of fractal nature, expressed by the usage of fractal geometry, due to the fact that its principles can adequately explicate morphology in a whole. In the domains of architecture and urbanism, previous research is predominantly carried out in the fields of design, construction, heritage preservation, human-building interactions and others ([1], [2], [3], [4], [5], [6], [7]).

Additionally, mentioned fractal approach is capable of characterising artefacts geometric features mathematically regarding style they belong to [8]. But, especially in the case of classical architectural orders, a specific newly investigated methodology is developed to qualify and classify belonging capitals as well as to identify/recognise such orders stylistically (by taking into account their morphometric/geometric characteristics, explicating the results mainly descriptively – by evaluating the obtained data visually) [9].

Therefore, the narrower aim of this Paper is to explicate the mentioned characteristics numerically/quantitatively by transposing already introduced stylistic-wise parameters (descriptors) [9] into the form of dynamics of their values (named "explicators"). The main research questions of this study are both how to express capital morphology by using dynamics of its parameters and, thus, how to numerically/quantitatively identify architectural order concrete capital belongs to.

The subject of this Paper is to establish relevant morphometric/geometric indicators in the form of explicators and qualifiers, enabling so to numerically express capital morphology, namely to quantitatively estimate levels of intra-similarity of capitals assumed to belong to the same order, and inter-dissimilarity of those assumed to belong to different ones. Indicators refer to corresponding/ descriptors (inherited from the previous subject-related research conducted by the same authors [9]) obtained by processing capital contours which are positioned in mutually equidistant transverse section planes (related to each of the chosen capitals, namely their digital 3D models).

The wider research aim refers to both: (a) a possibility to numerically/ quantitatively identify order a concrete fragment of capital belongs to in terms of recognising it computationally (as confidently as possible from the mathematical probability point of view), and (b) to perform morphology-wise capital segmentation (as a precondition of semantic one) – by employing artificial intelligence in terms of machine learning, primarily [10], [11].

2. METHODOLOGY

In order to reach the aims tasked, the main methodology principles are retrieved from the previous research [9], including the definition of indicators (descriptors and qualifiers) and relevant outputs obtained (descriptors values). However, so as the obtained results to be numerically/quantitatively explicable as much as possible, and thus morphometric changes described by trendlines easily detectable, the applied methodology is slightly "tuned". Consequently, descriptor trendlines are substituted in this research with those of explicators, expressed by dynamics of values of corresponding descriptors. Bearing in mind the fact that the exact spatial positioning (by using an adequate polar coordinate system) of morphology-wise excesses (morphometric marks of capitals of concrete order) is not considered here from the Paper topic point of view as well as the fact that capital contours from the set which refers to mutually equiangular radial section planes are not "informative" enough regarding the same reason, set of contours of transverse slicing is used here only (unlike it is a case in [9], where both of mentioned sets of contours are processed on an equal footing).

Indicators mentioned in Section 1. are expressed by both: several explicators of fractal and non-fractal nature (as an auxiliary one), and several corresponding qualifiers which are represented by arithmetically averaged values of analysed explicators – expressing so their global "from-section-to-section" changing rule. The nature of the established explicators and qualifiers are broadly explained in Sub-subsection 2.2.2.

2.1. **Starting considerations**

To draw scientifically acceptable conclusions, prerequisites and constraints listed in [9] are to be satisfied as mandatory (Morphometry/Geometry-related and ImageAnalysis-related ones).

2.2. **Methodology setup**

2.2.1. **Samples selection**

To elaborate on a sustainability of the established capital qualification, capital classification, and numerical/quantitative order identification criteria as well as a validity of defined principles of the aim-related methodology, three representatives (hereinafter: "triplet") per each fundamental classical architectural order are used (Doric, Ionic, and Corinthian). For a more detailed explanation of previously mentioned selection criteria, one can consult corresponding methodology setup principles described in [9].

2.2.2. **Indicators definition**

According to the purpose of this research, two types of explicators are defined: the main one – represented by dynamics of descriptors of fractal nature (related to the distribution of (multi)fractal dimensions of capital contours located in each of its transverse section planes – expressed by a unitless value), and the auxiliary one – represented by dynamics of descriptors of non-fractal nature (related to the distribution of areas bounded by the previously generated corresponding sets of contours – expressed by square metres). The auxiliary type of explicators is foreseen due to the same reasons as those of corresponding control descriptors [9]. Consistent with the fundamental meaning of the term "dynamics" (describing it as a changing rate or variation level between two neighbouring values of the same nature (namely, of descriptors inherited from [9]) divided by the adopted unit step of that variation (hereinafter: "AUS", namely, a distance between two consecutive section planes), following explicators are introduced: FractalExplicatorTransverse (hereinafter: "FET"), and AreaExplicatorTransverse (hereinafter: "AET").

FET describes a changing rate of fractal-wise descriptor values (FDTs inherited from [9]) along the transverse slicing direction, namely, a variation level between each two consecutive such values divided by AUS of that variation. AET describes a changing rate of non-fractal-wise descriptor values (ADTs also inherited from [9]) along the transverse slicing direction too, namely, a variation level between each two consecutive such values divided by AUS of that variation.

As in [9], two types of qualifiers are defined, as well: the first one which relates to arithmetically averaged values of explicators of fractal nature, and the second one which relates to arithmetically averaged values of explicators of non-fractal nature – both obtained separately for each triplet of contours defined by section planes of the same ordinal number, namely of the same slicing position in the corresponding triplet of capital samples of the same order (hereinafter: “1st”, “2nd”, and “3rd” sample).

Those types are named in this research as follows: FractalMeanTransverse (hereinafter: “FQT”), and AreaMeanTransverse (hereinafter: “AQT”). Having in mind the previously mentioned explicators typology as well as the fact that qualifiers are derived from, it is obvious that the firstly listed qualifier is also the main one, while the other one is the auxiliary.

2.2.3. **Quantifiers definition**

To achieve data-driven order identification/recognition (based on previously introduced indicators, namely explicators and qualifiers derived from), several quantifiers related to the desired number of AUSs (which approximately[5] correspond to capital canonical zones[6] they refer to) ought to be introduced. Ones, generally declared the most important, are following: (a) Number of Peaks[7]/Valleys[8], Their Extreme Values, and Distances between Those Extremes Expressed by Number of AUSs, (b) Density of Peaks/Valleys and Their Extreme Values, (c) Intervals between Each Two Consecutive Peaks/Valleys and Their Extreme Values, and (d) Amplitudes of Each Neighbouring Peak-Valley Pair, Their Extreme Values, and Distances between Those Extremes Expressed by Number of AUSs.

A number of the aforementioned capital canonical zones (signed here in Roman numerals (I, II,…)) vary from order to order as it is shown in Figure 1.

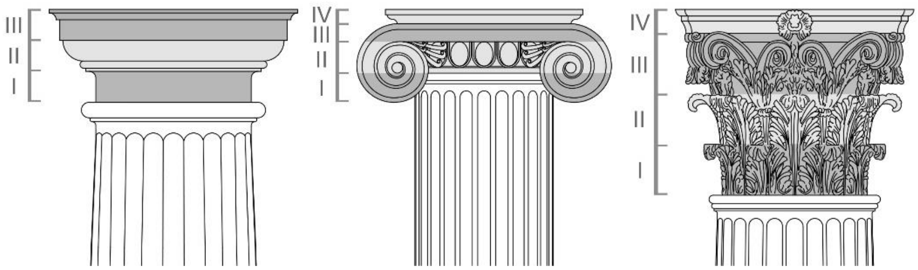


Figure 1. Marked Capital Canonical Zones of Doric, Ionic, and Corinthian Orders (from left to right) – Signed in Roman Numerals

[5] Proportion rules imply that the heights of capital canonical zones contain a number of AUSs which is not always an integer.

[6] Canonical zone of capital of concrete order is a segment of its mass whose height is defined with respect to the overall capital height according to corresponding proportion rules [12], [13].

[7] Peak is the value of indicator that refers to the case when behaviour of its change along the applied slicing direction is characterised by an increase-to-decrease transition.

[8] Valley is the value of indicator that refers to the case when behaviour of its change along the applied slicing direction is characterised by the decrease-to-increase transition.

Doric capitals generally consist of three visually recognisable morphology-wise zones, while Ionic and Corinthian ones consist of four such zones.

Bearing in mind the quantifiers listed above, due to the limited number of pages, Number of Peaks/Valleys are analysed only. Two classes of chosen quantifier are introduced: Number-of-Peak Quantifier (hereinafter: “NOP Qnt”), Number-of-Valley Quantifier (hereinafter: “NOV Qnt”).

3. INDICATORS AND QUANTIFIERS OBTAINING

3.1. Explicators calculating

According to the FET/AET definition (stated in Sub-subsection 2.2.2.), based on corresponding FDT/ADT descriptor values inherited from [9], with respect to equation (1)/(2), explicators calculation is performed by the usage of Excel.

$\boldsymbol{K}th\ FET_{(i\to(i+1))} = (\boldsymbol{K}th\ FDT_{(i+1)} - \boldsymbol{K}th\ FDT_{(i)})/AUS$, i=(1, n–1), K=(1, 2, 3)
where “n” is the total number of transverse section planes,
while “K” is the ordinal number of concrete capital sample (1)

$\boldsymbol{K}th\ AET_{(i\to(i+1))} = (\boldsymbol{K}th\ ADT_{(i+1)} - \boldsymbol{K}th\ ADT_{(i)})/AUS$, i=(1, n–1), K=(1, 2, 3)
where “n” is the total number of transverse section planes,
while “K” is the ordinal number of concrete capital sample (2)

3.2. Qualifiers calculating

According to the FQT/AQT definition (stated in Sub-subsection 2.2.2.), based on each triplet of corresponding previously obtained FET/AET explicators, with respect to equation (3)/(4), qualifiers calculation is also performed by the usage of Excel.

$FQT_{(i\to(i+1))} = (\boldsymbol{1}st\ FET_{(i\to(i+1))} + \boldsymbol{2}nd\ FET_{(i\to(i+1))} + \boldsymbol{3}rd\ FET_{(i\to(i+1))})/3,$
i=(1, n–1), where “n” is the total number of transverse section planes (3)

$AQT_{(i\to(i+1))} = (\boldsymbol{1}st\ AET_{(i\to(i+1))} + \boldsymbol{2}nd\ AET_{(i\to(i+1))} + \boldsymbol{3}rd\ AET_{(i\to(i+1))})/3,$
i=(1, n–1), where “n” is the total number of transverse section planes (4)

3.3. Quantifiers calculating

According to the NOP Qnt/NOV Qnt definition (stated in Sub-subsection 2.2.3.), based on each triplet of corresponding previously obtained FET/AET explicators namely on each FQT/AQT qualifiers derived from, with respect to equation (5)/(6) namely (7)/(8), quantifiers calculation is performed by the usage of Excel – per each capital canonical zone, separately.

$\boldsymbol{K}th\ NOP\ Qnt\ (FET) = \boldsymbol{K}th\ NOP\ Qnt\ (FET)\_I + \boldsymbol{K}th\ NOP\ Qnt\ (FET)\_II + \cdots,$
$\boldsymbol{K}th\ NOP\ Qnt\ (AET) = \boldsymbol{K}th\ NOP\ Qnt\ (AET)\_I + \boldsymbol{K}th\ NOP\ Qnt\ (AET)\_II + \cdots,$
K=(1, 2, 3), where “K” is the ordinal number of concrete capital sample,
while “I, II,...” are ordinal numbers of canonical zones of Kth capital sample (5)

$\boldsymbol{K}th\ NOV\ Qnt\ (FET) = \boldsymbol{K}th\ NOV\ Qnt\ (FET)\_I + \boldsymbol{K}th\ NOV\ Qnt\ (FET)\_II + \cdots,$

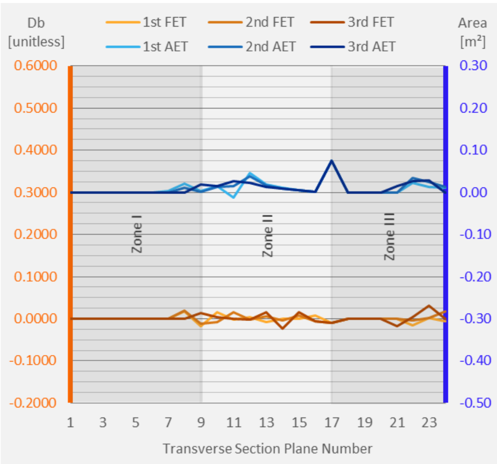
$\boldsymbol{K}th\ NOV\ Qnt\ (AET) = \boldsymbol{K}th\ NOV\ Qnt\ (AET)\_I + \boldsymbol{K}th\ NOV\ Qnt\ (AET)\_II + \cdots,$
K=(1, 2, 3), where “K” is the ordinal number of concrete capital sample,
while “I, II,...” are ordinal numbers of canonical zones of Kth capital sample (6)

$NOP\ Qnt\ (FQT) = NOP\ Qnt\ (FQT)\_I + NOP\ Qnt\ (FQT)\_II + \cdots,$
$NOP\ Qnt\ (AQT) = NOP\ Qnt\ (AQT)\_I + NOP\ Qnt\ (AQT)\_II + \cdots,$
while “I, II,...” are ordinal numbers of canonical zones of concrete order (7)

$NOV\ Qnt\ (FQT) = NOV\ Qnt\ (FQT)\_I + NOV\ Qnt\ (FQT)\_II + \cdots,$
$NOV\ Qnt\ (AQT) = NOV\ Qnt\ (AQT)\_I + NOV\ Qnt\ (AQT)\_II + \cdots,$
while “I, II,...” are ordinal numbers of canonical zones of concrete order (8)

4. RESULTS

The results are differently represented with respect to the fact whether they refer to the obtained values of indicators or quantifiers. So, first ones are in the form of six charts (3x2=6). Charts 1, 3, and 5. show transverse-wise trendlines triplets of explicators of both defined types (fractal and non-fractal), related to the triplet of capital samples of the same order. Charts 2, 4, and 6. show transverse-wise trendlines of qualifiers of the same previously mentioned types. Each qualifier trendline (as mean one) substitutes the corresponding triplet of explicator trendlines by “averaging” it (hereinafter: “Dor FQT”, “Ion FQT”, “Cor FQT” and “Dor AQT”, “Ion AQT”, “Cor AQT”).



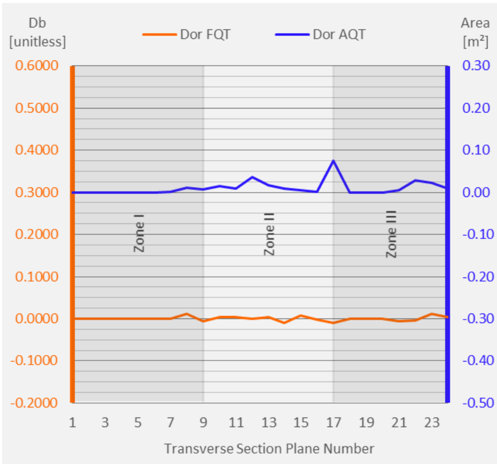
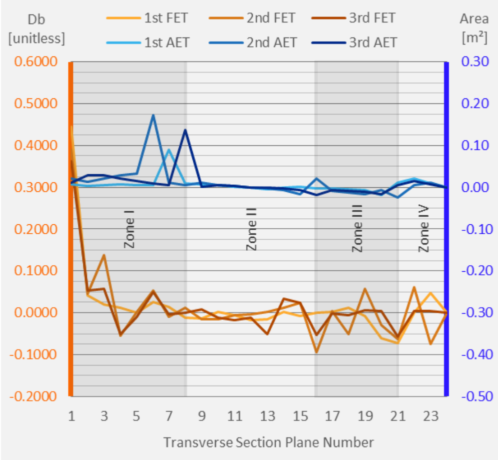


Chart 1. (left) Intra-order “Doric” Similarity: Transverse-wise Explicator Trendlines Related to the Triplet of Corresponding Capital Samples

Chart 2. (right) Transverse-wise Fractal and Non-fractal Qualifier Trendlines That Substitute Triplets of Corresponding Doric Explicator Trendlines



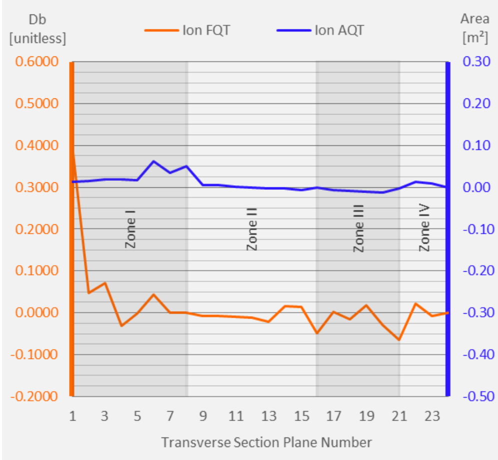
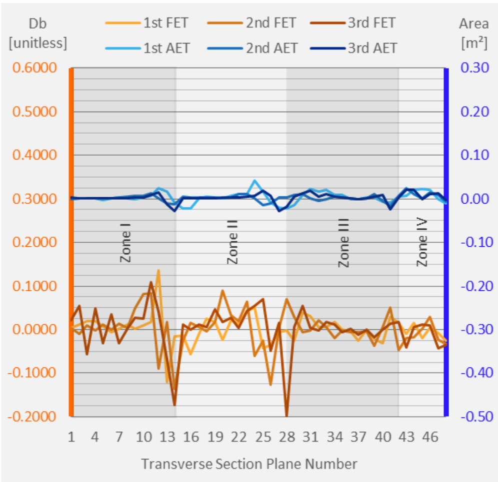


Chart 3. (left) Intra-order "Ionic" Similarity: Transverse-wise Explicator Trendlines Related to the Triplet of Corresponding Capital Samples

Chart 4. (right) Transverse-wise Fractal and Non-fractal Qualifier Trendlines That Substitute Triplets of Corresponding Ionic Explicator Trendlines



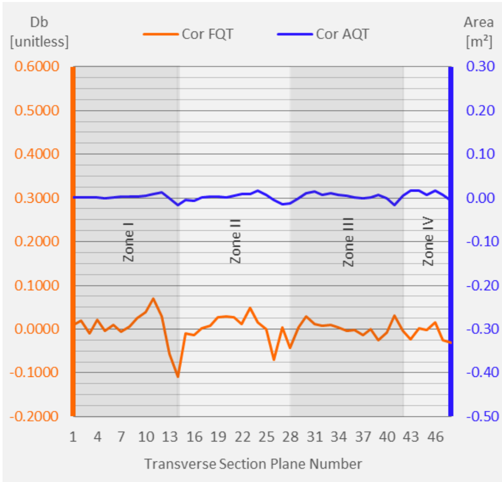


Chart 5. (left) Intra-order "Corinthian" Similarity: Transverse-wise Explicator Trendlines Related to the Triplet of Corresponding Capital Samples

Chart 6. (right) Transverse-wise Fractal and Non-fractal Qualifier Trendlines That Substitute Triplets of Corresponding Corinthian Explicator Trendlines

The quantifiers-related results are represented in the form of three tables (2+1=3) and variety of doughnut-charts derived from the corresponding filled-in results. Table 1. and Table 2. contain values of indicator-wise quantifiers regarding analysed orders and canonical zones of corresponding capital samples. Table 3. represents values of qualifiers numerical thresholds of fractal and non-fractal nature that relate to one of the examined orders only – the Corinthian one (due to its morphology-wise complexity – the greatest among analysed). Those thresholds are represented by minimal and maximal values of explicator-wise quantifiers and threshold means (qualifier-wise quantifiers) calculated by averaging.

Table 1. Intra-order Similarity: Values of Explicator-wise Quantifiers Regarding Analysed Orders and Canonical Zones of Corresponding Capital Samples

Table 1.				Canonical Zones of Selected Capital Samples											
				1st				2nd				3rd			
				I	II	III	IV	I	II	III	IV	I	II	III	IV
Analysed Explicator-wise Quantifiers: Number of Peaks / Valleys	NOP Qnt	FET	Dor	1	3	2		1	3	1		1	2	2	
			Ion	1	2	1	1	3	1	2	1	2	3	2	1
			Cor	4	4	4	2	5	5	4	1	5	6	5	1
		AET	Dor	1	3	1		1	2	1		1	2	1	
			Ion	2	1	0	1	1	2	1	1	2	1	1	1
			Cor	2	2	3	1	1	3	3	2	1	1	3	2
	NOV Qnt	FET	Dor	1	3	1		1	3	1		0	3	1	
			Ion	1	3	1	0	3	2	2	1	3	3	2	0
			Cor	3	4	4	2	6	4	5	0	5	6	4	2
		AET	Dor	1	2	1		1	1	1		0	2	1	
			Ion	2	1	1	0	2	1	2	0	1	2	1	0
			Cor	2	3	3	0	1	3	3	1	2	1	3	1

Table 2. (left) Inter-order Dissimilarity: Values of Qualifier-wise Quantifiers Regarding Analysed Orders and Corresponding Capital Canonical Zones

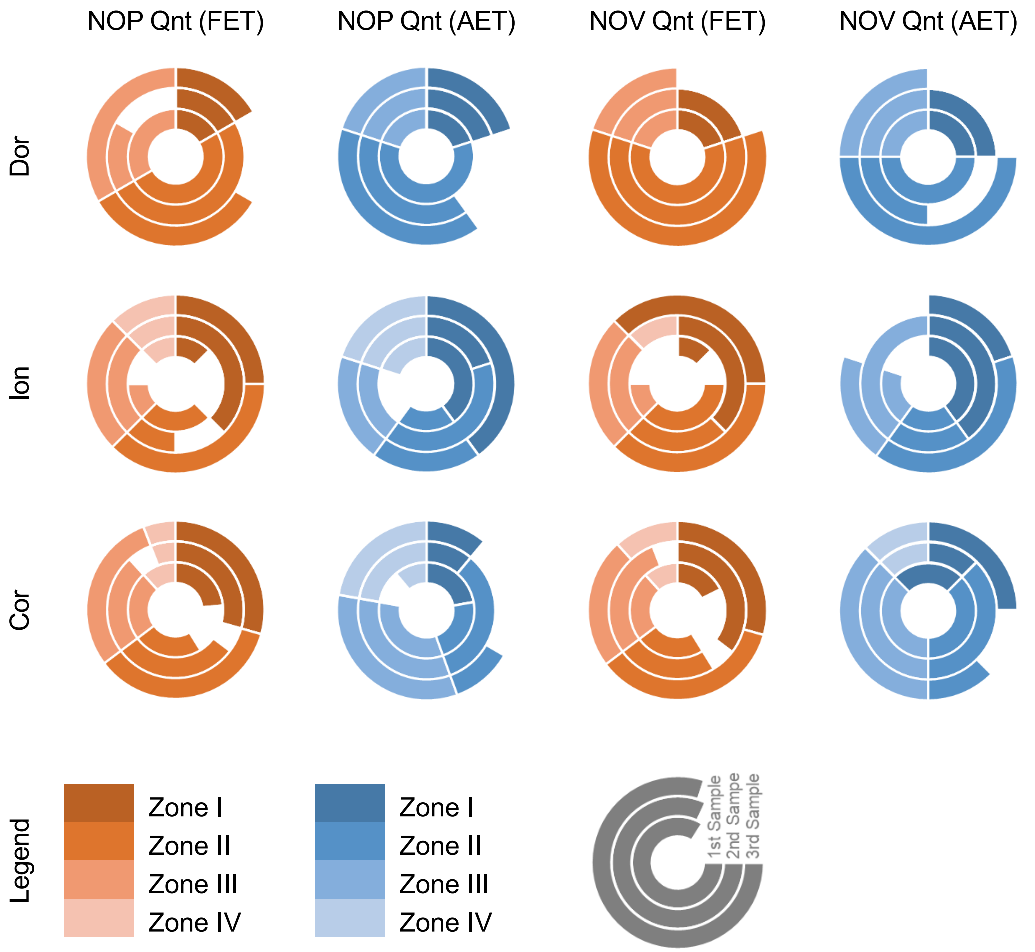
Table 3. (right) Corinthian Order Identification/Recognition: Values of its Qualifier-wise Quantifiers and Corresponding Thresholds (Min, Max) Related to Each Canonical Zone

Table 2.				Canonical Zones of **All Analysed** Orders			
				I	II	III	IV
Analysed Qualifier-wise Quantifiers: Number of Peaks / Valleys	NOP Qnt	FQT	Dor	1	3	2	
			Ion	3	1	2	1
			Cor	**4**	**4**	**5**	**2**
		AQT	Dor	1	3	1	
			Ion	3	1	0	1
			Cor	**2**	**3**	**3**	**2**
	NOV Qnt	FQT	Dor	1	3	1	
			Ion	3	2	2	1
			Cor	**4**	**4**	**4**	**2**
		AQT	Dor	1	2	1	
			Ion	2	1	1	0
			Cor	**2**	**3**	**3**	**1**

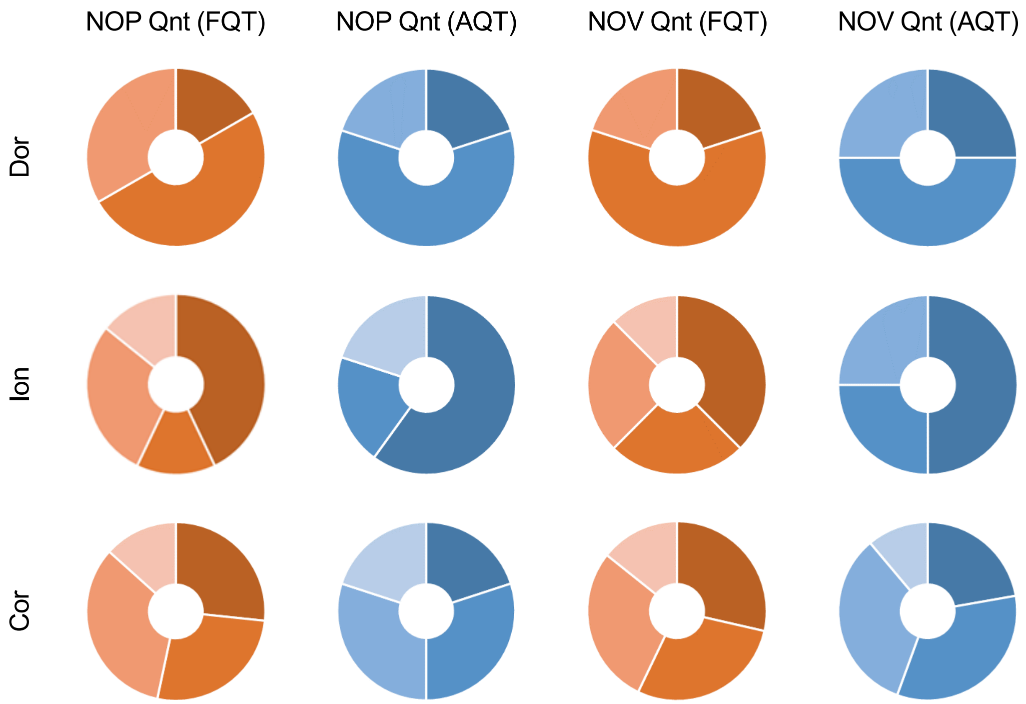
Table 3.			Canonical Zones of **Corinthian** Order			
			I	II	III	IV
NOP Qnt	FET	Min	4	4	4	1
	FQT	**Cor**	**4**	**4**	**5**	**2**
	FET	Max	5	6	5	2
	FET	Min	1	1	3	1
	FQT	**Cor**	**2**	**3**	**3**	**2**
	FET	Max	2	3	3	2
NOV Qnt	FET	Min	3	4	4	0
	FQT	**Cor**	**4**	**4**	**4**	**2**
	FET	Max	6	6	5	2
	FET	Min	1	1	3	0
	FQT	**Cor**	**2**	**3**	**3**	**1**
	FET	Max	2	3	3	1

Because of the facts that both capital heights differ from order to order and quantifiers values (which relate to the concrete canonical zone) might vary from sample to sample, to cross-reference the obtained results as reliably as possible, their relative values (calculated based on "absolute counting") are only compared. Consistent with the fundamental meaning of the term "relative", a percentage abundance of the analysed quantifiers values related to the concrete canonical zone is to be understood here with respect to their overall number that refers to the capital in whole. Given that the behaviour of trendlines shown in Charts 1, 3, and 5, namely, in Charts 2, 4, and 6 is described by explicators which are functionally dependent on descriptors inherited from [9] (as obtained from them arithmetically), namely, by qualifiers derived from corresponding explicators (by averaging them), the charts mentioned above (that demonstrate an intra-order similarity, namely, an inter-order dissimilarity as identically as those already elaborated in [9]) will not be discussed here, but only behaviours of the researched quantifiers read out from created doughnut-charts (Doughnut-charts 1, 2, and 3).

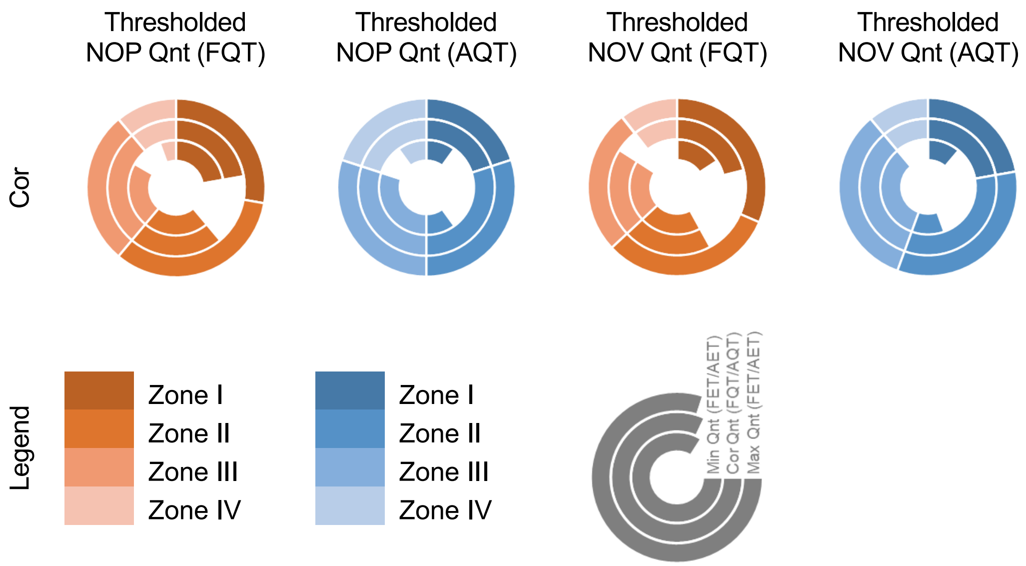
Doughnut-charts 1. Percentage Abundance of Fractal and Non-fractal Explicator-wise Quantifiers for Doric, Ionic, and Corinthian Order with Regard to Analysed Triplets of Capital Samples and Their Corresponding Canonical Zones



Doughnut-charts 2. Percentage Abundance of Fractal and Non-fractal Qualifier-wise Quantifiers Regarding Analysed Doric, Ionic, and Corinthian Order and Corresponding Capital Canonical Zones



Doughnut-charts 3. Corinthian Order Identification/Recognition: Percentage Abundance of its Fractal and Non-fractal Qualifier-wise Quantifiers Thresholded by Corresponding Min and Max Percentage Abundances of Explicator-wise Quantifiers Regarding Capital Canonical Zones



5. DISCUSSION AND CONCLUSION

Doughnut-charts 1. Mutually similar behavior of the explicator-wise quantifiers of both types (fractal: orange coloured and non-fractal: blue coloured), and of both classes (NOP and NOV) among the analysed capital samples from the same triplet can be declared almost identical when doughnut rings occupancy namely proximity of sizes[9] of their slices which relate to the same zone are pretty balanced[10], confirming so intra-order similarity. Slight deviations of doughnut rings occupancy that relate to some of the samples, regardless of orders they belong to (represented by certain blank parts of corresponding rings), could be caused by the following issues: either because of the used 3D models inadequacy (when ones do not conform with the originals from morphology-wise point of view) or because of morphometric non-compliance with strict canonicity.

Doughnut-charts 2. The more similar behaviour of the qualifier-wise quantifiers of the same order and class is (regardless of their type), the greater proximity of sizes of doughnut slices[11] will be, providing so more detectable inter-order dissimilarity. Even though doughnuts of the same class and type related to different orders might seem mutually almost identical (for example: Ion NOV Qnt (FQT) and Cor NOV Qnt (FQT)), corresponding doughnuts of the remaining analysed class and/or type do answer whether those quantifiers could be declared members of the same or mutually different orders. It is obvious that the larger number of analysed capitals (representative samples) is, the more aqurate sizes of doughnut slices and thus their intra-doughnut distribution (as well as the more reliably inter-order dissimilarity estimation) will be. In that case, as well, it is possible to estimate whether that distribution can be declared acceptable from the statistical probability point of view, by using previously defined relevant thresholds (tolerance).

Doughnut-charts 3. For the reason explained in Section 4., Dougnut-charts 3. are created only – based on data shown in Table 3. By observing containing doughnuts, it is obvious that corresponding "Corinthian" qualifier-wise quantifiers (whose canonical zone-related values are represented by sizes of the middle-ring-slices) belong to the corresponding (zone-related) tolerance ranges (defined by related Min (sizes of the inner-ring-slices) and Max thresholds (sizes of the outer-ring-slices)). Based on the usage of that stylistically known capital, satisfied mentioned condition (being conformed to the acceptable tolerance range) confirms scientific sustainability of the established approach.

It can be concluded that the presented innovative methodology (developed from [9] and slightly "tuned") brings a more reliable possibility to identify architectural order "stylistically unknown capital" belongs to – by using a newly introduced indicator (in the form of dynamics) to express its morphology numerically/ quantitatively. Future research will be dealt with software-wise automation of stylistic decoding steps (rough capital classification and order-belonging estimation).

[9] Size of the ring slice (which refers to the concrete canonical zone of the particular capital sample from the analysed triplet of samples) is a term related to the value of corresponding explicator-wise quantifier. (NOP Qnt (FET/AET)/NOV Qnt (FET/AET))

[10] Balanced occupancy of doughnut rings refers to the approximate "equality" of sizes of belonging slices related to the same capital canonical zone of the concrete order. Term "equality" implies the usage of previously calculated probabilistically acceptable thresholds (tolerance).

[11] Size of the doughnut slice (which refers to the particular canonical zone of triplet of capital samples of the concrete order – represented by that slice) is a term related to the value of corresponding qualifier-wise quantifier (NOP Qnt (FQT/AQT)/NOV Qnt (FQT/AQT))

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REFERENCES

[1] Yamu Claudia van der Laag, Frankhauser Pierre: **A multi-scale (multi-fractal) approach for a systemic planning strategy from a regional to an architectural scale**. *15th International Conference on Urban Planning, Regional Development and Information Society 2010*, Vienna, 17-26, 2010.

[2] Athanasiou Apostolos, Ebrahimkhanlou Arvin, Zaborac Jarrod, Hrynyk Trevor, Salamone Salvatore: **A machine learning approach based on multifractal features for crack assessment of reinforced concrete shells**. *Computer-Aided Civil and Infrastructure Engineering,* Vol. 35, No. 6, 565–578, 2020.

[3] Carpinteri Andrea, Spagnoli Andrea, Vantadori Sabrina: **A multifractal analysis of fatigue crack growth and its application to concrete**. *Engineering Fracture Mechanics,* Vol. 77, No. 6, 974–984, 2010.

[4] Ji Hui, Yang Xiong, Ling Haibin, Xu Yong: **Wavelet domain multifractal analysis for static and dynamic texture classification**. *IEEE Transactions on Image Processing*, Vol. 22, No. 1, 286–299, 2013.

[5] Devetaković Mirjana, Petruševski Ivana, Ćirović Ivana, Petruševski Ljiljana: **Fractal parametric models of urban spaces**. *Tehnicki Vjesnik.* Vol. 22, No. 6, 1547-1552, 2015.

[6] Ćirović Ivana: **Random curds as mathematical models of fractal rhythm in architecture**. *Spatium*. Vol. 1, No. 31, 79-84, 2014.

[7] Đorđević Đorđe, Ćirović Ivana: **Visual complexity of fractal rhythm**. *11th International Scientific Conference “Science and Higher Education in Function of Sustainable Development”.* Mećavnik-Drvengrad, Užice, 23-29, 2019.

[8] Capo Daniele: **The fractal nature of the architectural orders**. *Nexus Network Journal,* Vol. 6, No. 1, 30–40, 2004.

[9] Mitrović Djordje, Djordjević Djordje, Devetaković Mirjana, Djukanović Gordana: **Encoding/decoding capitals of classical architectural orders by using fractal geometry: Establishing methodology**. *9th International Scientific Conference on Geometry and Graphics, MoNGeometrija 2023*, Novi Sad, 153-167, 2023.

[10] Diara Filippo, Rinaudo Fulvio: **IFC Classification for FOSS HBIM: Open issues and a schema proposal for cultural heritage assets**. *Applied Sciences,* Vol. 10, No. 23, 8320, 2020.

[11] Quattrini Ramona, Carlo Battini, Mammoli Raissa: **HBIM to VR. semantic awareness and data enrichment interoperability for parametric libraries of historical architecture**, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2, 937–943, 2018.

[12] Vitruvius Pollio Marcus: **Deset knjiga o arhitekturi = De architectura libri decem** (M.Lopac, Trans.; R.Jadrešin Milić, Ed.). *Orion art*, Beograd, 2014.

[13] Chitham Robert: **The Classical Orders of Architecture** (2nd ed.). *Routledge*, London, 2005.

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